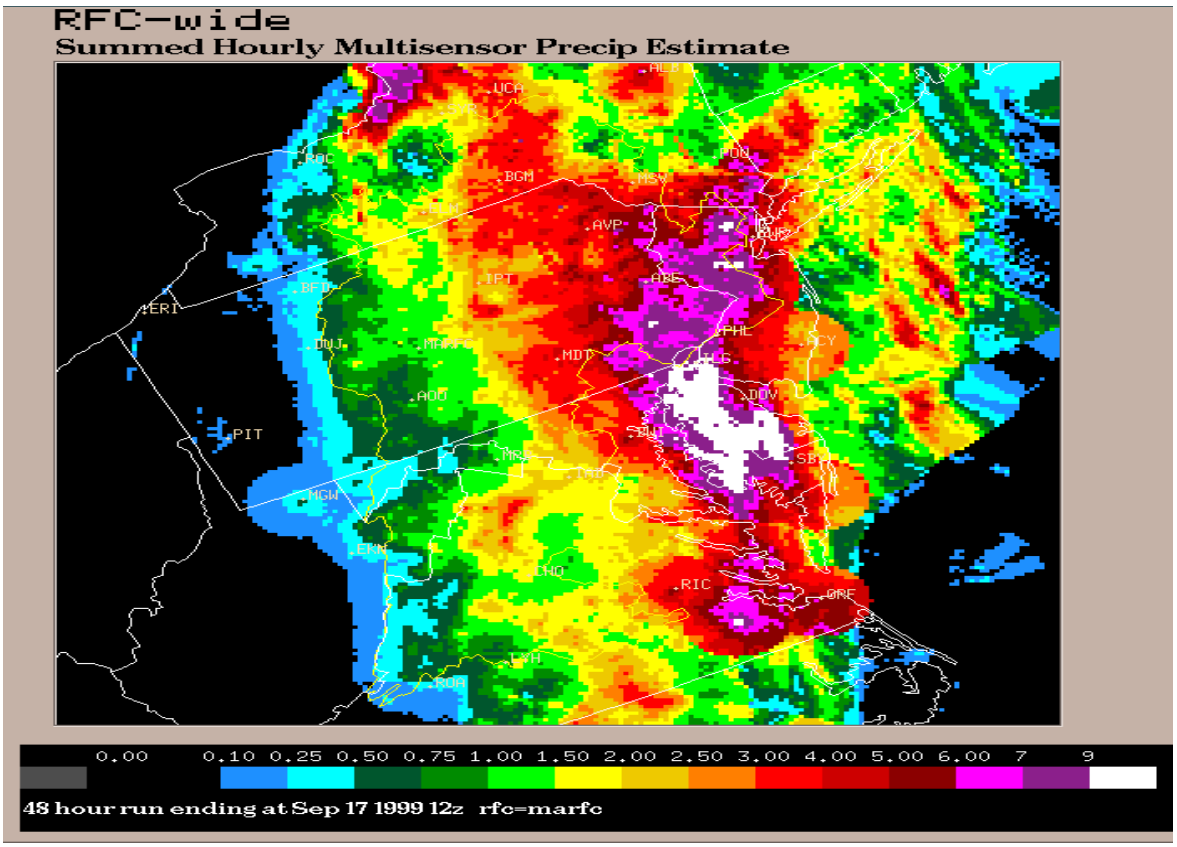
Second National Quantitative Precipitation Estimation Workshop

April 13-15, 1999



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National Weather Service
Office of Meteorology
Silver Spring, MD 20910

September 1999

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List of Acronyms and Abbreviations

ABR	Average Basin Rainfall
AE	Auto-Estimator
AFOS	Automation of Field Operations and Services
AGPI	Adjusted GOES Precipitation Index
ALERT	Automated Local Evaluation in Real Time System
AMBER	Areal Mean Basin Estimated Rainfall
AP	Anomalous Propagation
AR	Alaska Region
ASOS	Automated Surface Observing System
AWHPS	Area Wide Hydrologic Prediction System
AWIPS	Advanced Weather Interactive Processing System
CBRFC	Colorado Basin River Forecast Center
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CMAP	CPC Merged Analysis of Precipitation
CNRFC	California/Nevada River Forecast Center
CODE	Common Operational and Developmental Environment
COMET	Cooperative Program for Operational Meteorology, Education, and Training
CPC	Climate Prediction Center
CPU	Central Processing Unit
CR	Central Region
DHR	Digital Hybrid Scan Reflectivity
DMSP	Defense Meteorological Satellite Program
ECMWF	European Center for Medium Range Weather Forecasting
ELT	Equilibrium Level Temperature
EMC	Environmental Modeling Center
ER	Eastern Region
FFG	Flash Flood Guidance
FFT	Flash Flood Threat
FLS	Flood Statement
FPDT	Forecast Products Development Team
FSL	Forecast Systems Laboratory
GCIP	GEWEX Continental Scale International Project
GEO	Geostationary Satellite
GEWEX	Global Energy and Water Cycle Experiment
GIMPAP	GOES I-M Product Assurance Plan
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
GPI	GOES Precipitation Index
GSFC	Goddard Space Flight Center

GUI	Graphical User Interface
HDP	Hourly Digital Precipitation Product
HIWG	Hydrometeorological Information Working Group
HPC	Hydrometeorological Prediction Center
HPCC	High Performance Computer Center Proposal
HRAP	Hydrologic Rainfall Analysis Project
HRL	Hydrologic Research Laboratory
IFFA	Interactive Flash Flood Analyzer
IFLOWS	Integrated Flood Observing and Warning System
IR	Infrared
LAPS	Local Analysis and Prediction System
LCL	Lifting Condensation Level
LEO	Low Earth Orbiter
MAP	Mean Areal Precipitation
MAXPRA	Maximum Precipitation Rate
MIRRA	Microwave/IR Rain Rate Algorithm
MOS	Model Output Statistics
NASA	National Aeronautics and Space Administration
NAWIPS	NCEP Advanced Weather Interactive Processing System
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPA	National Precipitation Analysis
NPPU	National Precipitation Prediction Unit
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NWP	Numerical Weather Prediction
NWS	National Weather Service
NWSFO	National Weather Service Forecast Office
NWSO	National Weather Service Office
NWSRFS	National Weather Service River Forecast Center
OAR	Office of Atmospheric Research
OGP	Office of Global Programs
OH	Office of Hydrology
OHP	One-Hour Precipitation
OLR	Out-going Long Wave Radiation
OM	Office of Meteorology
OPI	Out-going Long Wave Precipitation Index
ORA	Office of Research and Applications
ORPG	Open Radar Products Generator
OSD	Office of Systems Development
OSDPD	Office of Satellite Data Processing and Distribution

OSF	Operational Support Facility
OTB	Operations Training Branch
OU	Oklahoma University
OWATADS	Open WSR-88D Analysis Testing and Display System
PDF	Probability Density Function
PBZ	Pittsburgh (NWSFO)
POES	Polar-Orbiting Environmental Satellite
PPS	Precipitation Processing System
PR	Pacific Region
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
PSP	Programmable Signal Processor
PUP	Principal User Processor
PW	Precipitable Water
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
RAP	Research Applications Program
RDA	Radar Data Acquisition
RFC	River Forecast Center
RFCPPS	River Forecast Center Precipitation Processing System
RH	Relative Humidity
RPG	Radar Products Generator
SCAN	System for Convection Analysis and Nowcasting
SG	Satellite-Gage
SGM	Satellite-Gage Model
SHEF	Standard Hydrometeorological Exchange Format
SPC	Storm Prediction Center
SSD	Scientific Services Division
SSHPS	Site-specific Hydrologic Prediction System
SSM/I	Special Sensor Microwave/Imager
STP	Storm Total Precipitation
TDL	Techniques Development Laboratory
THP	3-Hour Precipitation
TIROS	Television and Infrared Radiometer Observational Satellite
TOGA	Tropical Oceans and Global Atmosphere
TOVS	TIROS Operational Vertical Sounder
TPC	Tropical Prediction Center
TRMM	Tropical Rainfall Measurement Mission
USP	User Defined Product
USWRP	U.S. Weather Research Program
UW	University of Wisconsin
VIL	Vertically Integrated Liquid
VISIT	Virtual Institute for Satellite Integration Training
WATADS	WSR-88D Analysis, Testing and Display System
WWRP	World Weather Research Program

Executive Summary

The Second NWS Quantitative Precipitation Estimation (QPE) Workshop was held at the Cooperative Program for Operational Meteorology, Education and Training (COMET) in Boulder CO., from April 13 through 15, 1999. Participants included representatives from the following organizations: 1) NWS: Office of Meteorology (OM), Office of Hydrology (OH), the National Centers for Environmental Prediction (NCEP), Eastern Region, Central Region, Southern Region, Western Region, Alaska Region, Pacific Region, the Office of Systems Development (OSD) and the Office of Systems Operations (OSO); 2) The University Corporation for Atmospheric Research (UCAR): COMET & National Center for Atmospheric Research (NCAR); 3) the National Environmental Satellite, Data, and Information Service (NESDIS): Office of Research and Applications (ORA) and the Office of Satellite Data Processing and Distribution (OSDPD); 4) The National Aeronautics and Space Administration (NASA); 5) Cooperative Institute for Research in the Atmosphere (CIRA); 6) United States Bureau of Reclamation (USBR), and 7) Office of Oceanic and Atmospheric Research (OAR): National Severe Storms Laboratory (NSSL) and the Forecast Systems Laboratory (FSL).

Workshop goals included: 1) Summarize and examine the status of the QPE requirements established at the First National QPE Workshop; 2) Review and discuss operational techniques for the optimal use of existing QPE products; 3) Review current applied research and product development; 4) Review and discuss current and future AWIPS applications and decision tools which utilize QPE products; 5) Review current QPE training efforts and future plans; and 6) Develop group recommendations for applied research, product development, and communications infrastructure needed to satisfy future QPE requirements.

The workshop comprised 7 sessions. The title of each session along with a brief summary follows.

1. <u>QPE Requirements/Applications</u>

The workshop opened by reviewing requirements discussed at the first National QPE Workshop and included in the NWS Strategic Plan entitled "*The Modernized End-to-End Forecast Process for Quantitative Precipitation Information: Hydrometeorological Requirements, Scientific Issues, and Service Concepts*" (OM, 1999). (http://www.nws.noaa.gov/om/qpi_all_final.pdf.) Detailed requirements necessary to establish a national Quantitative Precipitation Forecasting (QPF) verification program and implement a National Precipitation Verification Unit (NPVU) at the NOAA Science Center in Camp Springs, MD, were presented. Verification data will enable the NWS to quantify and improve, through timely feedback, the performance of QPF products and assess the value added at each step of the NWS End-to-End (ETE) QPF Process. Furthermore, verification data will be utilized to ensure the ETE Forecast Process represents the most efficient use of resources to produce quality QPF for hydrologic services. A prototype system is scheduled to be implemented by November 2000. The quality assurance, format, transmission, and timely receipt of precipitation observations, multi-sensor ground truth analyses, and QPF products in support of the NPVU was also discussed.

2. <u>Operational Application of WSR-88D and Satellite-Based QPE: Lessons Learned and Suggestions for Effective use within AWIPS</u>

Representatives from the NWS Regions discussed a spectrum operational issues including: 1) the development of event-specific methodologies to select the most appropriate Z/R relationship; 2) the need to increase the spatial density, areal coverage, and accuracy of rain gage observations; 3) the implementation within AWIPS of advanced algorithms to quality control observations; 4) the utility of real-time satellite-based NESDIS Auto-Estimator rainfall estimates for hydrologic services; and 5) the pressing need to rapidly implement within AWIPS the functionality inherent in the Areal Mean Basin Estimated Rainfall (AMBER) Program.

An AWIPS flash flood decision assistance tool is being developed which is based upon the AMBER Program. This tool is entitled the Flash Flood Monitoring and Prediction (FFMP) application. FFMP will significantly expand upon the functionality inherent in AMBER and a prototype is undergoing testing at the Sterling WFO as a part of the 1999 System for Convection Analysis and Forecasting (SCAN) Field Test. A necessary and critical step in the implementation of FFMP is the delineation of watersheds down to a resolution of two square miles. Workshop participants stressed the need to define a consistent and scientifically sound methodology to delineate quality-assured flash flood watersheds nationwide. Use of AMBER at the flash flood prone Pittsburgh WFO since 1995, has yielded dramatically improved services and verification statistics.

3. <u>WSR-88D Based QPE</u>

The need for improved radar calibration and algorithm development dominated much of the discussion in this session. Given the sensitivity of radar-based estimates to calibration, many participants articulated the need to ensure WSR-88D data quality. Additionally, considerable discussion was focused on current work and future plans to improve the radar estimates produced within the WSR-88D precipitation processing subsystem (PPS). The mitigation of known radar deficiencies such as bright banding and range degradation were discussed along with the growing need to quantify the uncertainty in radar-based (and multi-sensor) estimates. While operational tests of PPS enhancements have shown impressive results, there is a need for further and focused algorithm development given the broad use and critical need for accurate "ground truth" precipitation products. Field representatives would also like an objective methodology developed which will support event-based Z/R relationship selection. Additionally, the US Bureau of Reclamation (USBR) has developed an algorithm that uses radar reflectivity data to estimate snow water equivalent and snow accumulation. It was recommended that the USBR snow accumulation algorithm (SAA) be implemented due to its successful field testing. Finally, it was agreed research and field testing focused on polarimetric radar measurements should be continued.

4. Satellite-Based QPE

The development and utility of global-, meso-, and storm-scale satellite precipitation estimates were discussed along with efforts to integrate lightning and radar data. Over the past few years, considerable resources have been focused on the development and validation of techniques to automate the generation of meso- and storm-scale satellite-based rainfall estimates. NESDIS representatives reported on the development of an experimental Auto-Estimator which provides in real time the following information: (a) instantaneous rainfall, (b) average hourly rainfall rates, and 3) 1, 3, 6 and 24 hourly hour accumulations. NESDIS plans to expand the Auto-Estimator algorithm to include SSM/I and AMSU data. These efforts are vital to the implementation of a high resolution multi-sensor optimal ground truth QPE product (i.e., RFC-wide). Considerable discussion was focused on the need to develop and test a prototype methodology which utilizes satellite-based rainfall estimates/data, calibrated using juxtaposed radar and gage data, to fill gaps in coverage between radars and mitigate known radar deficiencies.

5. QPE in Data Sparse Complex Terrain

Much of the western US, including Alaska and Hawaii have great difficulty estimating precipitation due to the complex terrain. The existing network of real-time hourly gage data and radar coverage is not sufficient. Western Region currently uses the Mountain Mapper software to estimate hydrometeorological parameters. Mountain Mapper uses a data set of estimated gridded climatic parameters which have been generated using point climatological and digital elevation model data. It was suggested that it would be operationally significant to implement Mountain Mapper in the Alaska Region as soon as PRISM data becomes available. Considerable discussion was also focused on utilizing precipitation estimates as an input for NWP forecasts. Improvements in NWP models have produced new NWP applications which include: data assimilation for latent heating, and input to a land data assimilation system for initialization of soil moisture and soil temperature. It was suggested Mountain Mapper procedures be introduced into the precipitation estimation procedures at NCEP.

6. Integrated Systems, Products and Training

Integrated systems such as AMBER and WHFS, and their implementation in the D2D via SCAN were discussed in this session. Several case studies highlighting AMBER's flash flood utility were presented. Flash flood prone WFO Pittsburgh (PBZ) has been using AMBER operationally in their service area since 1995. From 1995-1998 PBZ has dramatically reduced their False Alarm Ratio (FAR) from 0.44 to 0.15 and significantly increased their Critical Success Index (CSI) from 0.53 to 0.84. Moreover, PBZ's probability of detection has risen to a near-perfect .98 and their average lead time has doubled to 78 minutes. It is envisioned that the implementation of enhanced AMBER functionality via FFMP will yield significantly better flash flood services and verification results nationwide, hence the field requirements to rapidly implement AMBER functionality within AWIPS.

The development of higher resolution modernized Flash Flood Guidance and a Flash Flood Index were also discussed.

In the area of product development, the Storm Prediction Center (SPC) gave an overview of some of their development efforts. Over the past couple of years the SPC has diversified and become an all hazards weather center. In addition to convective products, guidance is provided for hazardous winter weather, fire weather and heavy rainfall. Training requirements were also discussed. Specifically the QPF Professional Development Series (PDS) and supporting Professional Competency Units (PCU) were presented along with a status of this development effort.

7. Workshop Summary and Recommendations

During the last day of the workshop extensive discussion yielded a list of over 25 recommendations. These recommendations have undergone review by session chairpersons and workshop participants. A draft report of the recommendations went out to all the session chairpersons in May for review, and then to all workshop participants in July. The result is a comprehensive set of recommendations intended to efficiently and effectively promote the QPE program. The status of these recommendations will be reported during the third national QPE workshop which is scheduled for the fall of 2000. The recommendations immediately follow.

Recommendations and Action Items

Session 1

QPE Requirements/Applications
Chairperson: Jim Gurka/OM

Recommendation 1A: The NWS Regions must ensure that complete RFC-generated Daily Hydrometeorological (HYD) Bulletins are transmitted to NCEP. These bulletins include all 24-hour precipitation gage reports used in NWSRFS. Some of these data are currently truncated at the OSO server. Additionally, the NWS must ensure these data are available and can be displayed at field offices through AWIPS.
Action: (Short-term) Make data available at each RFC via anonymous ftp - Regional HSD Chiefs (October 1999)
Status: As of July 1999 successful transmission of the HYD to NCEP.
NCEP/Sid Katz and Brett McDonald.
Action: (Long-term) Work with OSO to ensure all data gets to NCEP through the OSO server and can be displayed on AWIPS. OM/Dave Helms (September 2000)

Recommendation 1B: Establish 5-year accuracy milestones (e.g., bias, RMS error) for the Stage I (radar) and the Stage II-III (multi-sensor) QPE analyses.
Action: OH/Jay Breidenbach (February 2000)

Recommendation 1C: Establish a physically-based approach to determine the radius of influence used in the generation of the gage-only Stage II-IV analyses.
Action: OH/HRL/DJ Seo, NCEP/EMC/Mike Baldwin (May 2000)

Session 2

Operational Application of WSR-88D and Satellite-Based QPE: Lessons learned and suggestions for most effective use within AWIPS
Chairperson: Andy Edman/WR

Recommendation 2A: Define a consistent process, and identify the necessary resources to delineate flash flood watersheds and develop a GIS database for national implementation of high resolution, AMBER-size basins within AWIPS D2D via System for Convection Analysis and Nowcasting (SCAN) and Flash Flood Monitoring and Prediction (FFMP). This process should be based upon the Jendrowski-Jones methodology enhanced and employed by NSSL to delineate flash flood watersheds for 1) the 1997 SCAN field test at the Sterling WFO, and 2) AMBER implementation at other WFOs which in Pittsburgh, Honolulu, Tulsa, and Salt Lake City.
Action: OM/Tom Graziano & Michael Mercer, OH/Roger Pierce, PR/Paul Jendrowski,

ER/Bob Davis and Peter Gabrielsen, NSSL/Ken Howard, OU/Baxter Vieux, OSD/Stephan Smith (November 1999)

Recommendation 2B: Provide real-time, satellite-based rainfall estimates to Pacific Region.
Action: NESDIS/ORA/Rod Scofield (November 1999)

Session 3

WSR-88D Based QPE
Chairperson: Don Burgess/OSO

Recommendation 3A: Ensure WSR-88D data quality (calibration, clutter filtering). Radars are routinely calibrated to established specifications (+/- 1 dB accuracy and 50 dB clutter suppression). Required system checks are now part of WSR-88D Preventive Maintenance Inspections (PMIs). As PMIs are accomplished, data quality is being checked. A few years ago the PMC instituted a one-time OSF check of data quality for all systems. If/when another such check is needed, further PMC action will be required.
Action: Regional SOD, OSF/Tim Crum (ongoing)

Recommendation 3B: Because mosaics reveal problems in data quality, establish a mechanism whereby the OSF can identify and report problems at specific radar sites and report to the NWS regions or other agency representatives.
Action: OSF/Tim Crum, Regional SOD (June 2000)

Recommendation 3C: Plan research which will investigate objective processes (perhaps utilizing soundings and/or model output) which could facilitate field office selection of the most appropriate Z-R relationship. Hence it is important that a default product, based on a default Z-R relationship be computed in addition to products computed using alternate Z-R coefficients. This will enable for a stable set of bias statistics to be computed.
Action: OSF/Tim O'Bannon, NSSL/Ken Howard, OH/Jay Breidenbach (June 2000)
Note: Resources to be used for this are limited, and quick response may not be possible. If this is a high priority item, further coordination among OSO, OH, NEXRAD TAC, and the PMC may be necessary.

Recommendation 3D: Develop, test and validate additional Z-R relationships for 1) dry boundary layer/high-based convection, and 2) cool season stratiform precipitation. Develop and deliver training materials to the field.
Action: OSF/Don Burgess and Tim O'Bannon,
NSSL/Ken Howard, OH/Jay Breidenbach (June 2000)
Note: Resources to be used for this are limited, and quick response may not be possible. If this is a high priority item, further coordination among OSO, OH, NEXRAD TAC, and the PMC may be necessary.
Status: Two new Z/Rs have been developed (one approved for Reno, NV and one approved

for Albany, NY). These may be appropriate for all regional sites. Because of other tasking, it may take until March 2000 for OTB staff to have time to prepare training materials.

Recommendation 3E: Because of favorable test results and field feedback, implement USBR Snow accumulation algorithm (SAA) and vertical profile of reflectivity (VPR) range correction algorithms. Develop and deliver training materials to the field.
Action: OSF/Don Burgess & Andy White, HRL/DJ Seo &Dennis Miller (No sooner than December 2001)
Status: SAA implementation will require ORPG fielding and Open Build 2 (Open Build 1 is just a porting of legacy software). Contents of Open Build 2 not yet determined and timing is uncertain.

Recommendation 3F: Accelerate the development, testing and validation of dual-polarization techniques and their inter-comparison with current WSR-88D rainfall estimation techniques.
Action: NSSL/Dusan Zrnic, NCAR/Ed Brandes (ongoing)

Recommendation 3G: Accelerate the development and testing of the real time Z-S algorithm.
Action: WR/Andy Edman, NCAR/Roy Rasmussen (ongoing)

Recommendation 3H: Develop a methodology to quantify the uncertainty in the Stage I - III QPE products (this could include utilizing an ensemble of Z-R relationships, quantifying the error due to calibration, etc.). Furthermore, the NWS should account for this uncertainty in the verification of QPFs, and the initialization of atmospheric and hydrologic models. Resources to be used for this are limited, and quick response may not be possible.
Action: HRL/DJ Seo/OSF-Tim O'Bannon (September 2001)
Note: If this is a high priority item, further coordination may be necessary.

Note: For action items listed as ongoing, an update will be given at the next QPE workshop.

Session 4

Satellite-Based QPE
Chairperson: Rod Scofield/NESDIS

Recommendation 4A: Develop and test a prototype algorithm which utilizes satellite-based rainfall estimates to fill gaps in radar coverage and mitigate known radar deficiencies. Preliminary research should also be conducted to investigate the calibration of satellite-based estimates for use in a multi-sensor algorithm such as Stage III or RFC-wide.
Action: NESDIS/ORA/Rod Scofield, OH/HRL/Jay Breidenbach, NSSL/Ken Howard (August 2000)

Recommendation 4B: Continue development, testing, and validation of automated high temporal and spatial resolution multi-spectral, multi-platform satellite-based rainfall estimates and explore the utility of lightning data.
Action: NESDIS/ORA/Rod Scofield, NASA/Steve Goodman (ongoing)

Recommendation 4C: Subsequent to successful field testing and validation, develop an implementation strategy for automated satellite-based rainfall estimates (central vs. local) to optimize their operational utility.
Action: OM/Jim Gurka, NESDIS/ORA/Rod Scofield, NESDIS/OSDPD/John Paquette, Regional SSD Chiefs (October 2000)

Recommendation 4D: In light of the need for additional development of the Auto-Estimator, NESDIS/OSDPD/SAB should continue to produce manual IFFA/SPENES in support of NWS flash flood operations at local WFOs/RFCs.
Action: NESDIS/OSDPD/John Paquette (ongoing)

Recommendation 4E: Continue development of the SSMI-based Tropical Rainfall Potential (TRaP) Product.
Action: NESDIS/OSDPD/John Paquette (ongoing)

Session 5

QPE in Data Sparse Complex Terrain
Chairperson: John Schaake/OH

Recommendation 5A: Implement the Mountain Mapper/NWSRFS analysis technique in QPE procedures used at NCEP: 1) to produce daily QPE for LDAS (on a 1/8 degree grid), and 2) to calibrate global ensemble precipitation products.
Action: OH/John Schaake (December 2000)

Recommendation 5B: Test the Mountain Mapper point-to-grid interpolation procedure. Use re-sampling procedures to see how well observed values at gages can be estimated from surrounding gages. Compare the Mountain Mapper approach with potentially better methods.
Action: OH/John Schaake (July 2000)

Recommendation 5C: Develop and test downscaling techniques to use ensemble-based QPF products for river forecasting both in and outside mountainous areas.
Action: OH/John Schaake, NCEP/Brett Mcdonald (December 2000)

Recommendation 5D: Continue development and testing of NWP model (e.g., LAPS, ETA, etc) data assimilation techniques for both the national and local scales. This is important for the development of improved QPE and QPF, especially in complex terrain. This approach should optimally combine diverse data sources in a physically and

dynamically consistent manner. Implement and continue to update LAPS within AWIPS.
Action: NCEP/Mike Baldwin, FSL/Steve Albers, OH/John Schaake (ongoing)

Recommendation 5E: Provide Alaska Region personnel training (workshop) on the scientific and technical details and operational utility of the Mountain Mapper application as a pre-implementation training step. Training would begin when PRISM data becomes available.
Action: WR/Andy Edman, AR/Jim Kemper (As PRISM data becomes available)

Session 6

Integrated Systems, Products and Training
Chairperson: Roger Pierce/OH

Recommendation 6A: Implement WHFS and AMBER flash flood functionality in the D2D of AWIPS via SCAN.
Action: OSD/TDL/Stephan Smith, OH/HRL/Jon Roe (ongoing)

Recommendation 6B: Test the NSSL-OU Flash Flood Index (FFI) at WFO Sterling as a part of the future SCAN Field Test. Additionally, test the FFI at other WFOs (which may include WFOs PBZ and HNL). The Flash Flood Index (FFI) is an automated system that tracks the potential for flash flood by basin. The FFI is composed of both static factors (terrain, soils, and vegetation) and dynamic factors (precipitation rate and accumulation). Calibration and validation of the FFI can be accomplished with the aid of a physically-based runoff model. As part of the operational test there should include a comparison between the FFI and the HRL modernized FFG.
Action: OSD/TDL/Stephan Smith, OU/Baxter Vieux, NSSL/Ken Howard (July 2000)
OH/HRL/Tim Sweeney/Mike Smith

Recommendation 6C: Expand SCAN field testing to include at least one site per NWS Region. This will allow regions to prepare for the implementation of SCAN within AWIPS and allow for testing in climatically and topographically diverse areas.
Action: OSD/TDL/Stephan Smith (June 2000)

Recommendation 6D: The Minimum Basin Area (MBA) for AMBER implementation should be selected according to a consistent set of standards that permit a mosaic of flood prone basins so that comparisons are valid across regions and radar umbrellas. Factors which merit consideration when determining (MBA) include: 1) the geomorphology of the drainage network, climate, geology, vegetation, and other controlling factors; 2) potentially hazardous discharge points such as schools, hospitals, residential developments, or bridges; 3) the climatological distribution of precipitation producing phenomena (which directly impact rainfall rates and, thus average basin rainfall); 4) the time of concentration based upon a climatological return period and duration of precipitation, and 5) a minimum number of

radar bins which must be sampled per basin to compute the average rainfall rate and average basin rainfall; 6) MBAs in adjacent WFOs.
Action: OM/Tom Graziano & Michael Mercer, OH/Roger Pierce & Seann Reed, PR/Paul Jendrowski, ER/Bob Davis and Peter Gabrielsen, NSSL/Ken Howard & Ami Arthur, OU/Baxter Vieux, OSD/Stephan Smith (November 1999)

Recommendation 6E: Assess and document the value of implementing a specific GIS application in AWIPS to support NWS forecast and warning services. This may be particularly beneficial for flash flood operations, as it would enable high resolution precipitation estimates and forecasts to be mapped more accurately into small watersheds.
Action: OM/Bob Reeves (April 2000)

Session 1: QPE Requirements/Applications

1a. Implementation of a National QPF Verification Program: QPE Needs and Issues
(Brett E. McDonald)

The purpose of the national QPF verification program is to uniformly measure QPF performance by quantifying skill, assessing value at each step of the end-to-end forecast process, and determining appropriate verification methodologies. QPF performance can then be provided to the forecasters at the HPC, WFOs, & RFCs, modelers at the EMC & TDL, and NWS management to identify where improvement is needed. Timely verification statistics can aid in improving QPF performance. Eventually, the program will be applied to probabilistic QPF (PQPF). Details of the program can be found in section 11.3 of The Modernized End-to-End Forecast Process for Quantitative Precipitation Information: Hydrometeorological Requirements, Scientific Issues, and Service Concepts (Office of Meteorology, 1999).

QPEs are central to the national QPF verification program. The goal of the national precipitation verification unit (NVU) is to obtain the highest quality QPEs in which to verify QPFs. A variety of possibilities already exist including gauge point observations, gauge-based gridded analyses, WSR-88D gridded analyses, multi-sensor gridded analyses, etc. Quality control on the above-mentioned products is also an issue since inaccurate estimates can greatly affect verification results. Although great attention has been placed in recent years to obtain QPEs of greater spatial and temporal resolution, the quality of these QPEs is still questionable as well as the responsibility of quality control.

Verification statistics will be available for a variety of forecast increments, spatial domains, and temporal periods. Primary (traditional) statistics are computed for 6- & 24-hour forecast increments, spatial domains from the CONUS to NWS regions to RFCs to WFOs, and temporal periods from years to seasons to months to individuals events. The ability to compute statistics for unique parameters will also exist.

As of this presentation, no one verification measure completely relates the overall performance of QPF. Thus, a variety of measures will be computed to attempt to describe the accuracy and skill of QPF. Some of these measures are mean absolute error, threat score, bias score, Bayesian informativeness score, Heidke skill score, Brier score, etc. The NVU will actively participate in research with other groups to develop more appropriate verification measures and methodologies. Accurate climatological data are needed for the computation of some of these measures.

Verification of NWS QPFs will improve the quality, performance, and utility of the QPFs. The success of the national QPF verification program, however, is largely dependent upon the synthesis of many NWS agencies to provide scientifically-accurate precipitation information.

The NPVU has been in existence since August 1998. A variety of QPEs and QPFs are now being ingested into the verification system. Observed data include CPC 1- & 24-hour gauge reports, gauge reports from four RFCs, METAR & synoptic reports, and GCIP Stage IV analyses. Forecast data include model output from the NGM, Eta, AVN, MRF, & RUC2 as well as manual 6-hr, 24-hr, & 5-day HPC QPFs. Currently, GEMPAK is the basis for all data storage and processing. Transition to AWIPS will be a focus when the overall structure of the program has been established.

Accomplishments to date include the (re)establishment of the HPC 24-hour verification system. Six-hour and 5-day HPC QPF verification is near completion. The NVU is also participating in the QPF Process Assessment Team established by NWS Director Kelly.

Idealistically, the NVU will utilize 4-km gridded multi-sensor (gauge emphasis) quality-controlled precipitation estimates. Realistically, however, high quality 6- & 24-hour gauge reports from the RFCs are necessary. The transmission of the RFC reports to the NVU is currently hampered by operational limitations within the NWS. It is proposed that changes be made so that these reports are accurately transmitted or alternative transmission methods be explored such as anonymous ftp and/or the WWW. One-hour gauge reports are also needed as well as gridded Stage III/IV products.

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Session 2: Operational Application of WSR-88D and Satellite-Based QPE: Lessons learned and suggestions for effective use within AWIPS

2a. Eastern Region:

(Peter Gabrielsen, Deputy ER HSD)

The National Weather Service (NWS) Eastern Region (ER) uses a number of quantitative precipitation estimate (QPE) tools as part of normal operations. Based on lessons learned from experience, ER has a number of suggestions for the most effective use of various QPE tools within AWIPS.

The WSR-88D radar is a valuable tool for estimating precipitation accumulation and rates. To productively use WSR-88D estimation tools in AWIPS, operators must be able to adjust the Z/R relationships. A national policy should be developed which based on science and addresses coordination issues different individuals (WFOs/RFCs/Vendors) will have using multiple radars. Assumptions about uniform drop size distribution is also an issue and the implementation of a distribution model is needed.

One way to optimize the use of the radar is to bring all the multi sensor data into the AWIPS system, so the radar can be calibrated and verified. Multi sensor data fields will support Stage III precipitation processing and ultimately assist the river forecast process. Development of specialized precipitation processing subsystems for specialized applications such as the snow accumulation algorithm should be encouraged . Development of the highest priority applications should be encouraged.

The satellite auto-estimator concept was tested in ER, and while it shows promise, there is still much work to be done to improve the accuracy and timeliness of the products. Current satellite auto-estimator products do not meet the needs of the watch and warning program. However, in their current form, satellite auto-estimator products provided value added input to coordination products for both the WFOs (Nowcasts, SFDs, and QPFS) and RFCs (HMDs, HCMs, and QPFS). Further work with the satellite auto-estimator products should make the product compatible to D2D and WHFS formats and the algorithms should be resident as a local AWIPS application, this would improve product timeliness. The QPEs from satellites also should be mapped to small areas (1-200) square miles and should be accumulated in user selectable periods from (30 min,1 hr, 3 hr, 6 hr, and 24 hrs.)

ER believes QPEs will support hydrometeorological operations effectively within AWIPS if they are implemented and tested in different regions, with the results being provided to the developers and the field. Considerations must also be made to incorporated the applications into AWIPS and LDADS so they are operationally useful. Two-way communication is the key to successful implementation of QPE technology in the NWS as we move towards complete AWIPS implementation.

2b. Southern Region:

(Jerry Nunn, SR HSD)

(1) lack of suitable Z-R relation for all occasions -- need at least a couple of tropical relations to fall back on;
(2) precipitation underestimation in certain cases;
(3) unwieldy mosaicking of WFO QPFs.

2c. Central Region:

(Noreen Schwein, CR HSD)

*Bad DCP gages (bad zeroes due to clogged gages) result in underestimation of Stage III product.
*Stage II bias is affected by DCPs
*Range ring overlap still a problem in decreasing precipitation estimate.
*Not enough hourly observing gages for radar algorithms and Stage III processing.
*Missing HDP products continue to plague RFCs...even in AWIPS era.
*Radar generally underestimates precipitation

I. Need guidance for switching to tropical ZR.
   A. October 4, 1999 Kansas City storm:
      Radar estimates using default ZR, 50% low
      Post-storm review showed good estimates using tropical ZR
      When should the switch occur? (PW values, warm cloud depth?)

II. Satellite Precipitation Estimates
   A. Often late
   B. Wrong location
   C. Helps to reinforce forecast thinking if rain continues
   D. Helps if not looking/noticing radar
   E. Helps verify radar estimates
   F. IFFA homepage not used operationally

2d. Alaska Region:

(Jeff Perry, Senior HAS, AKRFC)

Current limitations of the WSR-88D in the mountainous northern climates of Alaska are complicated by incomplete radar coverage and by a sparse gauge network. Therefore, radar precipitation products cover only a very small portion of the state and estimates are only useful during the summer. In order to produce a statewide QPE product, continued research and development of applications which integrate POES and GOES satellite precipitation estimates will be needed to fill in the gaps over the data sparse regions of the state.

An improved terrain following hybrid scan installed at the Alaska WSR-88Ds in 1998 produced better rainfall estimates inside of 50 km. However, at longer ranges, severe beam blockage, range degradation and overshooting of the precipitation continue to cause problems. A snow algorithm with a Z-S relationship needs to be implemented at all of the Alaska radars, but future improvements also need to include seasonal or real-time Z-R/Z-S relationships being integrated into the precipitation processing algorithms.

The first Hourly Digital Precipitation Array (HDP/DPA), which is needed for the Stage II and Stage III applications, was not available at the Alaska River Forecast Center (AKRFC) until 1997. Since the deployment of AWIPS in the fall of 1998 the HDP product is now being ingested from all 7 Alaska radars. However, communication problems continue to cause outages which result in missing HDP products. The AKRFC plans to begin routinely running Stage II and Stage III during the summer of 1999.

The Alaska Region also plans to install the Mountain Mapper software after the Alaska PRISM data set is completed in the summer of 1999. This software will help in quality controlling gage data and should also provide better QPE estimates than any current methods.

Future methods for producing QPE will need to integrate all multi-sensor (radar, satellite, surface data, upper air data and aircraft data) information with scientific and meteorologically consistent processes. Continued research and support of software such as LAPS which is currently integrating much of this data needs to continue.

2e. Pacific Region:

(Paul Jendrowski, SOO NWSFO HNL)

Pacific Region continued work on the AMBER algorithm. The basin data base structure for AMBER was redesigned to be much more flexible in configuring basins and to allow for more efficient processing. Additional outputs were added for the Basin Rate of Accumulation and for 1 km by 1 degree, 256 level radar format products for ABR and Basin Rate of Accumulation. The radar format products are displayable on AWIPS with minor localization changes.

An ArcView GIS extension was created to support the creation of the AMBER basin data base from digital terrain data. The extension provides updated processing for delineating watersheds that is much quicker than the previous ArcView basin project. An advanced tool for "burning" streams into the terrain data was also added that provides more control than the previous manual procedure.

Session 3: WSR-88D Based QPE

3a. Multi-Sensor (Stage I-III) QPE Products and Supporting Algorithms: Current Status and Future Direction (Jay Breidenbach NWS, OH, HRL)

INTRODUCTION

Multi-sensor precipitation estimates are currently produced at WFO's using Stage II and at RFC's using Stage III post processing of rainfall estimates produced by the PPS (Stage I). Currently, the only inputs to Stage II and Stage III are the PPS estimates and rain gage data. Therefore, any improvements the raw radar estimates produced by the PPS will also lead to improvements of the Stage II and Stage III estimates. The Office of Hydrology continues to study and implement enhancements to all three stages of radar-based precipitation estimation.

STAGE 1 (PPS) Enhancements

In collaboration with the OSF, the Hydrologic Research Laboratory (HRL) has studied several enhancements to the PPS which have shown impressive results in research simulations. Two algorithms which could have a positive impact on the raw estimates produced by PPS are a Vertically Profile of Reflectivity (VPR) range correction algorithm, and a radar echo classifier technique which appears to be very effective at AP detection and removal.

USE OF RADAR CLIMATOLOGY

It is possible to derive improvements to the hybrid scan based on thesholding reflectivity climatologies or precipitation rate from each tilt angle (fig 1). These, climate based hybrid scans take into account beam blockage caused by buildings, trees, and other obstructions not resolved by beam geometry and the digital terrain data. The climate based hybrid scans also appear to reveal azmuthal pointing errors at the RDA.

Even with a perfect hybrid scan, the "effective" radar coverage is less than 230 km due to

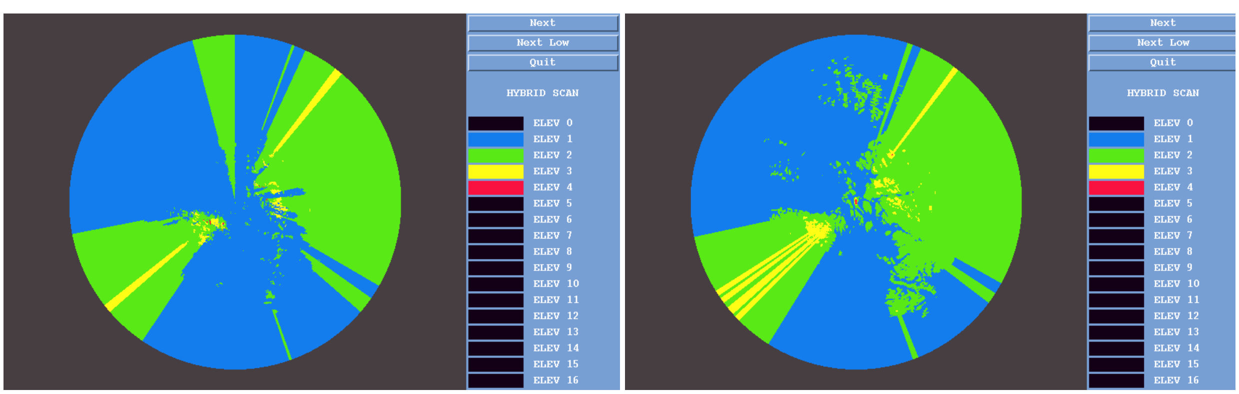

Figure 3 Seattle, WA (KATX) hybrid scan; a) based on placing a threshold on the frequency of a given precipitation rate from each tilt angle; b) default terrain-following hybrid scan based on beam geometry and terrain data.

range effects which are more severe where higher tilts are used. To define "effective" radar coverage, the climatology of the Hourly Digital Precip Array (HDP) can be computed for each radar. Once the radar climatology has been defined, either in terms of mean rainfall or frequency of rainfall, a threshold can be applied to that climatology, below which the radar estimates should not be trusted. An example of the radar-derived rainfall climatology and corresponding area of radar coverage is shown in figure 2. It is important to consider the true radar coverage when constructing multi-radar mosaics of precipitation.

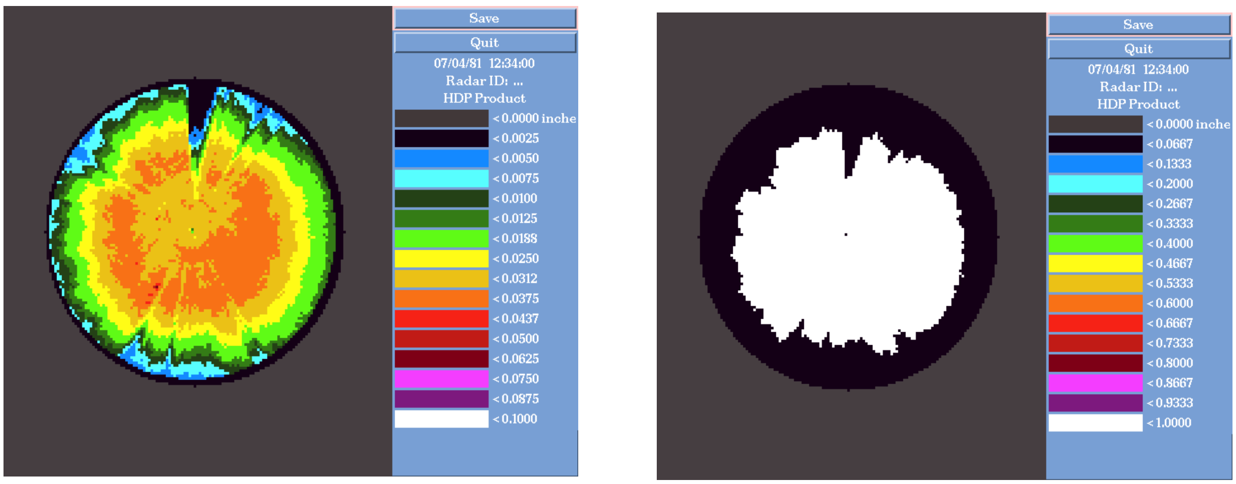

Figure 2 Blacksburg VA (FCX): a) Frequency of radar-derived rainfall; b) Effective radar coverage pattern based on thresholding frequency of rainfall. Black area indicates no or poor coverage. White area indicates good coverage.

MULTI-SENSOR PRECIPITATION ESTIMATES

The current Stage III algorithm does not make optimal use of overlapping radar coverage when creating multi-radar mosaics. Therefore, Stage III is being overhauled so that it can provide the framework for comprehensive, RFC-wide, multi-sensor rainfall estimation utilizing radar, raingage, satellite and other environmental information.

The RFC-wide multi-sensor rainfall estimation algorithm will have ability to compute and display gridded rainfall fields based on radar, bias corrected radar, rain gage, and multi-sensor estimates. Each of these gridded rainfall fields will cover the RFC area of forecast responsibility as defined for a portion of the national HRAP grid.

The input will include Digital Precip Arrays (DPAs) generated hourly at each individual WSR-88D RPG in RFC forecast area. The logic for deciding which radar covers a given grid point will be based on the lowest available coverage in terms of height above sea level. Grid points which are not well observed by a given radar due to beam blockage or far range effects (as defined by radar climatology) will not be mosaicked onto the RFC grid.

A real time radar bias correction algorithm will be run on data from each radar site based on hourly gage radar pairs The gage data used to create these gage-radar pairs will be available in the

RFC data base and will include multi-hourly gage reports which have been time-distibuted to create hourly values. Bias correction factors will be applied to grid points corresponding to the individual radars which they represent, creating the bias corrected rainfall feild.

The gridded rain gage only field will be created by applying an objective analysis technique (Single Optimal Estimation) to the rainfall measurements at gage locations.

The multi-sensor rainfall field will be created by merging the bias corrected radar field with rain gage observations through optimal estimation. This will technique tends to place more weight on gage values and less on the radar estimate for grid points located near rain gages. For grid points not located near a gage, more weight is placed on the radar value. The Optimal estimation technique will also estimate rainfall in areas where there is no radar coverage by searching for near by radar data and gage data to interpolate to the missing grid points.

In addition to the actual rainfall fields, the height of radar coverage above sea level and a map showing which radar covers which grid point will be computed and displayed.

An example showing the height of coverage field, radar mosaic, bias-adjusted radar mosaic, and multi-sensor field is shown in figure 3.

Future enhancements to the RFC-wide multi-sensor precipitation estimation algorithm will incorporate Satellite-derived precipitation. In addition, IR satellite data will be compared with gridded surface temperature data to help delineate areas of AP contaminating the radar-derived precipitation field. Another future enhancement will use the height of radar coverage arrray in combination with the height of the freezing level (as defined in the RUC) to delineate areas of radar-derived precipitation which have been derived near or above the freezing level.

The Graphical User Interface will be similar to the existing Stage III GUI and will allow the user to implement radar and gage manual quality control . Improvements to the GUI will allow the user to remove AP, draw in precipitation on the RFC grid and to display the new group of gridded field data generated by RFC-wide.

3b.The WSR-88D Precipitation Processing Subsystem-Enhancements and Future Plans
(Tim O'Bannon, OSF)

INTRODUCTION

The Precipitation Processing Subsystem (PPS) was developed by the National Weather Service (NWS) Office of Hydrology (OH) Hydrologic Research Laboratory (HRL) in the early 1980's for implementation into the Weather Surveillance Radar-1988, Doppler (WSR-88D) network (Ahnert, et al. 1983 and Ahnert et al. 1984). It was designed to generate real time, high resolution rainfall estimates to assist NWS forecasters in providing accurate and timely flash flood warnings and to use as input to NWS River Forecast Center (RFC) models. During the ensuing years, research at HRL and the Operational Support Facility (OSF), as well as numerous field reports and studies, have led to a number of PPS changes intended to enhance the radar-based precipitation estimates.

The following description is abridged to emphasize the changes which have been made to the PPS. A more detailed description of the PPS is available in Fulton, et al. (1998).

Algorithm Adaptable Parameters

The WSR-88D software contains a large number of variables (called "adaptable parameters") which can be changed in real-time to allow fine tuning and seasonal or regional adjustment of the algorithms. Since algorithm products can be very sensitive to parameter changes, a tri-agency

(NWS, Air Force Air Weather Service, Federal Aviation Agency) working group has established levels of authority for changing the parameters. These are explained in the Federal Meteorological Handbook, No. 11, Part A (1991). Many of the PPS enhancements have involved modifying the adaptable parameters. For clarification, the author will capitalize adaptable parameter names in this paper.

PPS DESCRIPTION

The PPS processes WSR-88D base reflectivity data through a series of four algorithms to generate rainfall accumulation products.

- Preprocessing Algorithm - Combines the most representative reflectivity data from the lowest four tilts into a single "hybrid" scan of reflectivity data.
  - Noisy data filter. Filters out isolated points of moderate to high reflectivity and replaces all anomalously high reflectivity values with a more reasonable value (MXREF).
  - Beam blockage correction. Corrects the incoming reflectivity data for radar beam blockage using site-specific, terrain-based blockage information (Occultation data) created by off line OSF software.
    - Adds corrections (from 1 dBZ to 4 dBZ) for partial blockages (< 60%)
    - Interpolates reflectivity data across areas of complete blockage with small azimuthal extent ($\leq$2 deg)
    - No correction is applied if the azimuthal extent of complete blockage is greater than 2 degrees.
  - Hybrid reflectivity scan. Assembles the "hybrid" reflectivity scan using a site-specific Hybrid Scan data file created by the same off line software that created the Occultation data file. For each range and azimuth, the Hybrid Scan data file defines the lowest unblocked tilt that clears the terrain.
  - Bi-scan optimization. At medium to far ranges from the radar, a two-stage "bi-scan optimization" technique is used to determine whether reflectivity data from the lowest tilt should be used.
    - Performs a Tilt Test to check for clutter contamination caused by anomalous beam propagation (AP). The Tilt Test compares the decrease in area of rainfall between the lowest tilt and the second tilt. If the decrease exceeds a threshold (MXPCT), the lowest tilt is rejected.
    - If the low tilt is not rejected, at each azimuth and range between a minimum (MNRBI) and maximum (MXRBI) range, the Preprocessing algorithm uses the highest reflectivity value from the first or second tilt. This step is called "Bi-scan Maximization."
- Rate Algorithm - Converts "hybrid" reflectivity scan into rainfall rates.
  - Reflectivity to rainfall rate conversion. Uses the exponential Z/R relationship $Z = CZM * R^{CZP}$, where Z is the reflectivity in $mm^6 m^{-3}$, R is the estimated rainfall rate in mm hr^{-1}, CZM is the multiplicative coefficient, and CZP is the power coefficient.
  - Average rate bins. Averages the (1 deg by 1 km) rainfall rate estimates to obtain (1 deg by 2 km) rate bins.
  - Rainfall rate threshold. Caps the rainfall rate in the rate bins at a threshold

(MXPRA).

  - Time continuity. Performs a Time Continuity test to remove any scans that appear to have sudden and unreasonable echo development or decay. The Time Continuity test compares the area of precipitation between a minimum and maximum range. The rate of change of area is acceptable if it doesn't exceed a threshold.
- Accumulation Algorithm - Averages rainfall rates from the previous and current scans to compute estimated (scan to scan) accumulations at each bin.
  - Hourly accumulation. Computes an hourly precipitation estimate each scan from the last 60 minutes of rainfall rate data. Computes a "clock hour" total on the hour.
  - Storm total accumulation. Computes a storm total precipitation estimate from all the scan-to-scan accumulations since the last one hour period without rainfall.
  - Missing data periods.
    - Interpolates accumulations across small missing periods and notes the missing periods on the products.
    - No corrections are applied for longer missing periods, but the period are also noted on the effected products.
- Adjustment Algorithm - Applies an hourly estimate of gage/radar bias.
  - Computing bias. The Mean Field Bias (MFB) computation is being planned for implementation into AWIPS build 5. The Adjustment algorithm will not become operational until the MFB values are made available.
  - Operator selection. If the operator selects, rainfall accumulations will be multiplied by the bias.
- PPS Products - Most PPS products are described in detail in Klazura and Imy (1993).
  - Graphical
    - Hybrid Scan Reflectivity (HSR)
    - One-Hour Precipitation (OHP)
    - Three-Hour Precipitation (THP) - Sum of latest three "clock hour" totals
    - Storm Total Precipitation (STP)
    - User Selectable Storm Total Precipitation (USP) - User selectable time period, sum of up to 24 out of the past 30 "clock hour" totals)
  - Digital
    - Digital Hybrid Scan Reflectivity (DHR)
    - Hourly Digital Precipitation Array (DPA)
  - Alphanumeric
    - Supplemental Precipitation Data (SPD)

PPS IMPROVEMENTS

- Data Quality
  - Radar Calibration. The OSF is continuing to develop improved radar calibration techniques and guidelines. Combined with training of radar maintenance personnel and increased diligence by field sites in maintaining system calibration, the quality of the base reflectivity data has improved significantly since the WSR-88Ds were first deployed. Considering that a 3 dBZ calibration error (not uncommon in the

early years of deployment) will create a 64 percent bias in the rainfall estimate at the default Z/R relationship, improved calibration may be the single most significant enhancement in PPS estimates.

- ○ Clutter Filtering. Clutter filtering at field sites has also improved as the result of training, site awareness, and OSF guidance. Proper clutter filtering is critical in minimizing the contamination of PPS products by ground targets. However, improper clutter filtering can significantly decrease rainfall estimates in regions with non turbulent wind fields.

- Adaptable Parameters. Many improvements in PPS products have been obtained by refining and regionalizing the values of WSR-88D adaptable parameters. In addition, the authority (initially at OSF level) for changing the values of some of the PPS parameters has been delegated to the local WSR-88D Unit Radar Committees (URCs).
  - ○ Mitigating Hail contamination. The maximum reflectivity threshold (MXREF) was originally used to remove hail contamination while maintaining high enough rainfall rates to identify flash flood events. Using a single reflectivity value is a simple correction to a complex problem, but there are no other readily available techniques to mitigate hail contamination. The original default value for MXREF (60 dBZ) allowed hail contamination to create small regions of unrealistic rainfall in PPS estimates. Shortly after the deployment of the first WSR-88D, the OSF lowered the default value for MXREF to 53 dBZ, and in the following years a number of sites received authority to modify MXREF to values ranging from 51 to 55 dBZ. The OSF Build 9 software changed the structure of the Preprocessing algorithm and made it necessary to increase the value for MXREF and to instead use the maximum allowable precipitation rate (MXPRA) threshold to remove hail contamination. All sites have been authorized and encouraged to modify the value of MXPRA as shown in the following table.

RECOMMENDED VALUES FOR MAXIMUM PRECIPITATION RATE	*MXPRA (mm hr^{-1})*	*Equivalent MXREF**
Arid - High Plains Spring	***75***	***~51 dBZ***
Central Plains Spring, High Plains Summer	***100***	***~53 dBZ***
Central Plains Summer, Gulf Coast Spring	***125***	***~54 dBZ***
Tropical - Gulf Coast Summer	***150***	***~55 dBZ***

** Assumes $Z = 300 * R^{1.4}$*

  - ○ AP Removal. The Preprocessing algorithm Tilt Test has proven to be an inefficient AP removal technique, particularly in regions where AP is embedded in precipitation. In addition, the Tilt Test often rejects regions of stratiform or orographic precipitation as AP. The original default value for MXPCT (50%) was found to remove excessive amounts of low tilt precipitation, frequently causing significant PPS underestimates. The OSF has increased the default value for

MXPCT to 75%. Some sites (particularly western U.S. mountaintop locations) which have very little AP and frequently observe stratiform or orographic rainfall have received authority to set the MXPCT to 99%, effectively disabling the Tilt Test logic.

  - Bi-scan Maximization. Bi-scan Maximization was designed to compensate for temporarily blocked radials, but its overwhelming effect has been to greatly enlarge the region of "bright band" contamination. The OSF has recommended that the minimum range (MNRBI) and maximum range (MXRBI) for Bi-scan Maximization both be set to 230 km so the process is disabled.
  - Z/R Relationship. The default WSR-88D radar/rainfall rate relationship ($Z = 300 * R^{1.4}$) appears to be fairly accurate in deep, convective rainfall events. However, the relationship significantly underestimates rainfall in warm process tropical and orographic rain events. The OSF is recommending that sites use a "tropical" relationship ($Z = 250 * R^{1.2}$) developed by Rosenfeld, et al. (1993) during those events. The "tropical" relationship more than doubles the precipitation estimates in heavy rain (above 45 dBZ) when compared with the default Z/R relationship. The two adaptable parameters used to modify the Z/R relationship are the multiplicative coefficient (CZM) and the power coefficient (CZP).

- Recent Software Enhancements
  - Terrain-based Hybrid Scan file. The optimum height requirement in the original site-specific Hybrid Scan data file created anomalous circular discontinuities in the PPS products near the radar (O'Bannon, 1997). The OSF developed a modified terrain-based Hybrid Scan data file that mitigated the discontinuities and distributed the modified Hybrid Scan data file to the field in the Fall of 1998. The modified Hybrid Scan also lowers the tilt used by the PPS over much of the area within 50 km of the radar. This improves precipitation estimates in cases where the original Hybrid Scan caused overshooting, particularly in orographic and stratiform events.
  - OSF Software Release Build 10. The latest OSF software release (delivered Fall 1998) contained the following PPS changes:
    - A graphic Hybrid Scan Reflectivity (HSR) product to provide users with the ability to see the reflectivity data that is use by the PPS.
    - The current values of all PPS adaptable parameters were appended to the DPA product to assist RFCs.

FUTURE CHANGES

- Near Future
  - Open RPG. The current WSR-88D Radar Product Generator (RPG) is hosted on a proprietary and archaic Concurrent mainframe computer system. Expanding the processing capability of the Concurrent system is financially prohibitive and ongoing maintenance costs are becoming excessive. The RPG software is being rehosted to open architecture hardware (Unix workstation). In addition to significantly lower costs for expansion and maintenance, open architecture should facilitate the change process. The delivery of Open RPG (build 1 - functionally equivalent to WSR-88D build 10) to the field should begin during the year 2000.
  - Mean Field Bias algorithm. HRL has developed a Mean Field Bias (MFB)

algorithm planned for implementation into AWIPS build 5. This algorithm is an extension of the Stage II precipitation processor logic and uses parallel estimation at multiple temporal scales to generate a table of multiplicative biases (Seo et al 1997, Breidenbach et al. 1998, and Fulton et al. 1998). The MFB output appears to be more accurate and reliable than the PPS code (particularly in regions with few rain gages). In addition, performing the Bias computations in AWIPS (which routinely collects and maintains rain gage data) removes the need for the rain gage data to be shipped to the WSR-88D.

The PPS Adjustment algorithm in the Open RPG will be modified significantly to utilize the output from the MFB algorithm. All the current logic that computes a bias will be replaced with software that reads in the table of multiplicative biases and determines the optimum bias by comparison with an operator supplied adaptable parameters. As in the current Adjustment algorithm, the operator will be allowed to select whether or not to apply the bias. Additionally, the Supplemental Precipitation Data (SPD) product will be modified to remove the rain gage data and both the SPD and Digital Precipitation Array (DPA) products will be modified to contain the MFB bias table and the applicable adaptable parameter information.

- Planned For Open RPG Build 2 (~2001)
  - <u>Modify PPS Adjustment algorithm to remove the Bias calculation logic</u>
  - <u>Implement Radar Echo Classifier algorithm to identify AP-based ground clutter.</u> The National Center for Atmospheric Research (NCAR) and ERL Forecast Systems Laboratory (FSL) have developed a Radar Echo Classifier (REC) algorithm that uses "fuzzy logic" to classify radar targets by type (Pratte et al. 1997, Keeler et al. 1998, and Kessinger et al. 1999). In its initial version, the REC will generate a graphic product that depicts the bin by bin likelihood that the radar target is clutter (most likely caused by AP). This AP/clutter identification product should assist operators in making clutter filtering decisions.

    In future builds, the PPS Preprocessing algorithm will be modified to use the REC AP/clutter identification output to mitigate contamination of precipitation estimates (replacing the crude Tilt Test logic in the current Preprocessing algorithm). AP/clutter identification information from the REC should also allow the use of reflectivity data from the lowest tilt nearer to the radar, improving PPS products and simplifying some of the Hybrid Scan decision logic.
  - <u>Implement Snow Accumulation algorithm.</u> The US Bureau of Reclamation has developed an algorithm that uses radar reflectivity data to estimate snow water equivalent and snow accumulation (Super and Holroyd, 1998). The Snow Accumulation algorithm (SAA) has been operationally evaluated (offline in real-time) at several sites and it is being proposed for implementation into the WSR-88D Open RPG build 2. Since the SAA relies on the accuracy of the base reflectivity data, improvements in base data quality (better calibration, clutter filtering, AP/clutter identification, etc.) should directly improve Snow estimates.
- Ongoing Study Areas
  - <u>Refine Vertical Profile of Reflectivity range correction algorithm.</u> HRL is developing logic (based on Andrieu and Creutin 1995, Andrieu et al. 1995, and

Vignal et al. 1997) to calculate the vertical profile of reflectivity (VPR) for removing range biases from the precipitation estimates. Preliminary results show the VPR can significantly mitigate the range bias in stratiform and tropical storm rain estimates. The VPR even appears to remove some of the radial artifacts in PPS products caused by Occultation and Hybrid Scan logic. If operational evaluation continue to be so positive, the VPR could be implemented into Open RPG build 3.

- Evaluate Probabilistic Quantitative Precipitation Estimation. HRL and the OSF are beginning to investigate the use of PPS to generate probabilistic quantitative precipitation estimates (PQPEs) using offline PPS software. In simplified design, the Rate and Accumulation algorithms will be run in an ensemble process using multiple Z/R and adaptable parameter solutions. The PQPE results will be output as probabilistic density functions, allowing the PPS products to be tailored to the needs of the users.
- Develop Radar Echo Classifier to identify additional targets. NCAR has shown evidence that the REC can identify precipitation targets and have begun development of logic to compensate for the negative effects of clutter filtering on precipitation estimates. NCAR is also beginning to evaluate the use of the REC to discriminate between convective and stratiform precipitation, to discriminate between rain and snow, and to identify clutter "residue".
- Evaluate dynamic Hybrid Scan. Currently, the Preprocessing algorithm uses a terrain-based site-specific Hybrid Scan data file to determine which tilt contains the most representative reflectivity data. The Hybrid Scan data file for each site is generated (along with the Occultation data file) at the OSF using offline software and is based on the following two rules: 1) if the beam is blocked by more than 50%, use a higher tilt, and 2) if the bottom of the beam is within 500 feet of the terrain, use a higher tilt at that range. The rationale for the "500 feet" rule is to help prevent the PPS from using clutter contaminated data. The AP/clutter information from the REC algorithm should allow a more precise and more reliable test to prevent clutter contamination. In addition, it should frequently allow the use of uncontaminated data from lower tilts, thus providing move representative reflectivity data to the PPS.

  A basic assumption in the use of the Hybrid Scan data file is that the first four tilts are identical for each radar Volume Coverage Pattern (VCP). Planned implementation of optimized WSR-88D scan strategies will likely cause this assumption to be untrue, i.e. the VCPs will not have identical low tilts.
  Using offline PPS software, HRL and the OSF are beginning to investigate the impact of replacing the current Hybrid Scan data files with a dynamic decision process. This process will likely require the use of blockage information (to maintain the 50% rule). Currently, a crude representation of the beam blockage information is contained in the Occultation data file but higher resolution blockage data can easily be generated by the offline software. In addition, improved beam blockage information (see next paragraph) may replace the Occultation data.
- Develop improved beam blockage correction. HRL is investigating the use of the long term statistical observation of WSR-88D reflectivity data to measure actual

beam blockages at each site (Breidenbach et al. 1999). Initial results indicate that long term analysis of the base data can improve beam blockage correction both by resolving near field beam blockage at a finer scale than is possible when using coarse (90 meter resolution) digital terrain data and by quantifying the blockage caused by non-terrain objects, i.e. trees, buildings, towers, etc. In addition, the statistical information may help sites clearly define and correct azimuthal pointing errors.

- PPS-related Changes Planned For Open RPG Build 3 And Beyond:
  - <u>Modify Precipitation Detection Function.</u> The current Precipitation Detection Function (PDF) logic does not consistently perform its primary function (ensuring the radar mode is correctly set during significant weather events) without considerable negative impact on field sites. The performance has been so bad at some sites that the operators use unrealistic adaptable parameters to override the PDF functionality.

    The secondary function of the PDF is to determine whether the radar reflectivity data is from precipitation or clear air targets (AP/clutter) and to report that information to the PPS. The PDF has not been particularly skilled at performing this function either, and when field sites override the PDF it can cause a significant underestimation in PPS products.

    HRL and the OSF will investigate alternative methods to ensure correct weather mode and to diminish the impact of non-weather targets while allowing the operators to exercise nondestructive control over the process. In addition, we will investigate the use of other logic (REC output, etc.) to determine what radar reflectivity data should be converted to precipitation estimates.
  - <u>Implement VPR range correction algorithm</u>
  - <u>Significant modifications to Preprocessing algorithm</u>
    - Replace Tilt Test logic and part of Hybrid Scan decision process with output from REC AP/clutter identification
    - Implement dynamic Hybrid Scan technique to support VCP modifications
    - Replace Occultation data file with improved beam blockage correction information
    - Apply VPR range corrections
  - <u>Implement PQPE functionality into PPS</u>
  - <u>Improve clutter filtering process</u>
    - Automated filtering and reflectivity compensation using REC output
    - Open RDA
- <u>Polarimetry</u>

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3c. Progress on the NCEP "Stage IV" Hourly Multi-Sensor U.S. Precipitation Analysis

(Michael E. Baldwin NWS/NCEP/EMC/GSC)

A prototype, real-time, hourly, multi-sensor national precipitation analysis, known as "Stage IV", has been developed at the National Centers for Environmental Prediction (NCEP) in cooperation with the Office of Hydrology (OH). This analysis merges two data sources that are currently being collected in real-time by OH and NCEP. Approximately 3000 automated, hourly raingage observations are available over the contiguous 48 states via the GOES Data Collection

Platform (DCP) and ASOS. In addition, hourly digital precipitation (HDP) radar estimates are obtained as compressed digital files via the AFOS network. The HDP estimates are created by the WSR-88D Radar Product Generator on a 131 x 131 4-km grid centered over each radar site. The data analysis routines, including a bias correction of the radar estimates using the gage data, have been adapted by NCEP on a national 4-km grid from algorithms developed by OH ("Stage II") and executed regionally at NWS River Forecast Centers (RFC).

The first product with a completed prototype was the national mosaic of radar precipitation HDP estimates. This radar-only product consists of nearly 140 WSR-88D radars which report to NCEP in real-time via AFOS. Each individual radar estimate is merged together on the 4km national Hydrologic Rainfall Analysis Project (HRAP) grid and bins which contain more than one radar estimate are averaged together using a simple inverse-distance weighted average. Currently, there is no quality control of the HDP estimates, such as removal of anomalous propagation.

In contrast to the simple radar-only mosaic technique, the analysis schemes used in the gage-only and multi-sensor analyses utilize optimal estimation theory. These were developed by Seo (1998). The schemes are fundamentally similar, and optimally estimate rainfall fields using raingage and radar data under partial data coverage conditions. This is preferred over previous statistically-based techniques because it takes into account the variability due to fractional coverage of rainfall, as well as within-storm variability. By objectively taking the spatial coverage into account, more accurate estimates of the rain versus no-rain area are obtained. Accurate delineation of this area is as important as accurate estimation of rainfall within the rain area. One of the underlying assumptions in the radar-gage analysis scheme is that the radar estimates are unbiased. Currently, radar estimates are bias-adjusted prior to the multi-sensor analysis by the technique developed by Smith and Krajewski (1991).

During this prototype phase, the Stage IV will omit manual quality control steps that are a hallmark of the RFC "Stage III" analyses. However, some initial quality control steps have been implemented into the current Stage IV system. A list of consistently bad raingages has been created, so that observations will be ignored from these reporting stations in the analyses. This list was subjectively determined by examination of numerous cases where the gages reported heavy rainfall for several hours while nearby gage and radar reports contained zero rainfall. As of this writing, a total of six gage stations have been omitted from the analysis, four in California, one in northeast Kansas, and one in New York. The only other quality control step currently in use involves a gross check on gage data, making sure no reports greater than 5in/hr get into the analysis system.

Near-future (0-12 month timeframe) NCEP improvements will focus on automated quality control procedures that utilize a host of NCEP and NESDIS national meteorological databases as filtering tools for such things as anomalous propagation. In addition, the radar bias algorithm will likely be modified to more closely follow the sample bias given the current hour's radar and gage estimates [Seo et al (1997)]. Operational implementation on the IBM-SP is also planned for 1999. Eventually, the Stage IV will incorporate automated, hourly, 4-km GOES IR satellite-derived precipitation estimates developed by NESDIS, which is available over both sea and land. A so-called "final" 24h accumulation analysis is also planned, which will include the higher resolution 24h gage data available from the RFCs. Upgrades to the Stage II algorithms from OH/HRL will be included as they are produced. Eventually, Stage IV will consist of overlays of regional Stage III analyses once they are available via AWIPS from the RFCs.

Finally, as a companion to the Stage IV products described above, NCEP is maintaining an archive of gage-only, radar-only, and multi-sensor products for purposes of comparison and assessment. A one-week archive of these products is available via anonymous ftp at ftp.ncep.noaa.gov in the /pub/gcp/precip/stage4/ directory. A longer-term tape archive of the Stage IV is also being maintained at UCAR/NCAR as part of the GCIP database for research purposes. WWW access to current Stage IV products, images, archives, and updated information can be found at http://ftp.ncep.noaa.gov:8000/gcp/htmls/hdpprec.html.

Longer term plans are to develop a "true" multi-sensor analysis, integrating satellite, radar, and rain gage data, along with information from a mesoscale NWP model. Variational data assimilation techniques (3DVAR, for example) will allow information on the state of the atmosphere and physical processes to be utilized while incorporating raw data from a wide variety of sources.

3d. Dual Polarization Rainfall Estimation: Open Systems Polarimetric Upgrade -- Status and Plans (Dusan Zrnic/NSSL)

Nationwide measurement of areal precipitation is currently made using the recently completed network of WSR-88Ds. While these radars provide significant enhancements to our understanding of the physics and dynamics of convection, no fundamental change in the way estimates of precipitation are made has emerged. Because there is no direct relation between radar reflectivity and precipitation, it is probably futile, after 45 years of attempts, to refine empirical relations between precipitation and reflectivity any further. Given the advancements in polarimetric radar technology in the last 20 years, now is a propitious time to investigate the capability of this technology to provide accurate estimates of rainfall over small and large areas.

NSSL's initial investigations of the problem started with exploration of two fixed polarimetric methods to estimate rainfall: One $R(K_{DP})$ uses the specific differential phase, K_{DP}), which has several advantages over measurements of the reflectivity factor Z. The other, $R(K_{DP}, Z_{DR})$ can compensate for the variation of the drop size distribution which, although less detrimental to $R(K_{DP})$ than R(Z), still affects the former. Examination of 15 storm events in Oklahoma revealed that $R(K_{DP})$ performs very well and that $R(K_{DP}, Z_{DR})$ is slightly better. But of these 15 cases, 11 occurred during the warm season (May, June) for which these relations are well matched to the rain type. The remaining 4 cases occurred in February through April; of these two were outliers with fractional bias of 26% and - 55%. This and further recent evidence suggest that existing polarimetric methods are not always adequate for estimating rainfall. Hence the following two questions: 1)" What is the reason for occasional unsatisfactory performance of the $R(K_{DP})$?", and 2) "What is the best rainfall estimation that can be achieved with radar polarimetry?"

There are strong reasons to believe that, when existing polarimetric methods fail to adequately estimate rainfall, a significant cause is the variability in drop size distribution (DSD). Data from ten storms, observed over the Little Washita river basin (which contains 42 densely spaced automated rain gages) have been obtained with the S-band Cimarron polarimetric radar. Examination of one-hour areal accumulations shows that radar can significantly overestimate and/or underestimate actual rainfall depending on the stage of the storm development and the corresponding rain regime. Both conventional and polarimetric methods for rainfall measurement tend to overestimate actual rainfall if large raindrops dominate the DSD. On the other hand, DSDs skewed towards small drops cause both methods to underestimate rainfall. The $R(K_{DP})$ relation, however, is less susceptible to DSD variations than the R(Z) method. If only the rain accumulation over the areas is needed then the cumulative differential phase along the beam, $Ö_{DP}$ is most robust.

To overcome the influence of DSD on polarimetric rainfall estimates a method is proposed whereby precipitation is classified and for each class a matching relation is applied to obtain the amounts. Classification is made using a fuzzy logic approach with all available radar polarimetric variables involved. The proposed scheme discriminates between rain of different intensity, rain mixed with hail, and rain consisting mostly of large drops in low concentration. The latter class is usually associated with early stages of convection and updraft regions. Mean differential reflectivity Z_{DR} for each class is then used in combination with K_{DP} to estimate rainfall separately within the area of the particular rain regime.

Path for addition of polarimetric capability to the WSR-88D is as follows: 1) Modest research and development effort is underway to evaluate if a scheme for simultaneous transmission and reception of orthogonally polarized waves is viable. In this scheme the polarimetric variables, important for precipitation identification and measurements, are available while all the current WSR-88D capabilities remain intact. 2) The proposed scheme will be tested on the NOAA/NSSL research and development radar. These tests will commence as soon as the new signal processor is incorporated into the system and appropriate software is developed. 3) In parallel with the engineering tests NSSL in collaboration with the University of Oklahoma and NCAR will continue do develop the method to classify and quantify precipitation. The main source of data will be the large archive (over 200 tapes) collected by the Cimarron polarimetric radar since 1992; other data sources include S-Pol radar and possibly CSUCHILL. 4) The tests will culminate in the Joint POLarizaiton Experiment (JPOL), to be conducted at the earliest in the year 2002 with the goal to demonstrate operational use of the technology.

Because completion of the upgrade to the signal processor and control circuitry on the WSR-88D is scheduled for 2004, polarimetric upgrade could start in 2006.

3e. Results of the NCAR Program in Radar Rainfall Estimation

(Ed Brandes/NCAR)

In 1996 the National Center for Atmospheric Research (NCAR) began a program for improving radar and satellite estimation of precipitation. The primary goals are to (1) improve WSR-88D (radar reflectivity-based) precipitation techniques, (2) determine the benefits that might be gained if the WSR-88D is modified for polarimetric radar measurements, and (3) improve earth satellite-based estimation methods. Goals are being met by collocating NCAR's S-band, dual-polarization radar (S-Pol) with local WSR-88Ds. A diverse dataset is being acquired. To date, field experiments have been conducted in Colorado (summer of 1996), Colorado (winter 1996-1997), Kansas (spring of 1997), and Florida (summer of 1998).

So far, studies have been conducted that compare radar reflectivity estimates of rainfall from collocated radars and examine the utility of the specific propagation phase parameter for estimating rainfall. Rainfall estimates derived from WSR-88Ds at Denver, Colorado and Wichita, Kansas have been found to have relatively small bias (1.07 and 1.05) and high correlation coefficient with gauge observations (0.77 to 0.95). Moreover, radar reflectivity estimates from collocated radars closely agree. Correlations between rainfall fields derived from WSR-88D measurements and those from S-Pol were typically 0.98. This suggests that a large component of the radar rainfall estimate error originates with meteorological factors--probably spatial and temporal variations in dropsize distributions.

Experiments with the specific propagation phase (Kdp) reveal that this parameteris comparable to radar reflectivity. Bias factors with reflectivity and Kdp are highly correlated. A problem with Kdp rainfall estimates is the occurrence of wide spread negative values with some stratiform rain events. The negatives are attributed to radar reflectivity gradients and possibly sidelobes. Benefits for the Kdp parameter demonstrated in our studies are an insensitivity to beam blockage and anomalous propagation. Also, the propagation phase measurement can be used to verify the radar hardware calibration.

Recent studies with radar and raindrop disdrometer data collected in Florida show that the differential reflectivity measurement (Zdr) can be used to estimate the median diameter of raindrops. Rainfall estimates can be improved by adjusting radar reflectivity measurements for the presence of relatively small drops (high rain rates) or large drops (low rainfall rates).

3f. USBR Snow Accumulation Algorithm (SAA)

(Dr. Edmond W. Holroyd, III, U.S. Bureau of Reclamation)

1. The principle investigators, Dr. Arlin B. Super and Ed Holroyd, worked with numerous others. The illustrated site is KENX (Albany, NY).
2. Snow has a different dielectric constant and more complicated shapes than rain. Furthermore, the SAA may sometimes be contaminated by the "bright band" effect caused by melting snow. We use the same equation form but calibrate to Ze rather than Z.
3. Most recording gages are near airports, which are especially windy sites. Cooperative gages may also lack shelter from the wind. A graph from previous Canadian work indicates that standard Universal gages catch only a third of available snowfall at only 5 m/s wind speeds if they are unshielded.
4. This gage site on Grand Mesa shows our ideal for a gage: a clearing in a conifer forest and an Alter wind shield around the gage. Measurements then differ insignificantly from snowboards.
5. Measuring snow by radar and by gage has numerous concerns. Gages that are not sheltered from the wind record less than the actual snowfall. Gages can have additional measurement problems. Radar measurements can be affected by ground clutter, blockage, and terrain clearance. Sample volume differences between radar and gages can be eleven orders of magnitude.
6. We use the standard occultation corrections. For the hybrid scan file we need to get as close to the ground as possible while avoiding ground clutter and blockages. The O'Bannon hybrid scan file is therefore superior to that for the PPS for our SAA purposes. We reformat the files in ASCII to allow customization by a text editor. We use a simpler coding in addressing the hybrid scan file. Snow has a typical reflectivity range from -10 to +40 dBZ. We raise the lower value to +4 to help avoid virga.
7. The advection scheme, created for our first SAA version, was deleted because it did not improve the results and took too much computer time to integrate upwards through the wind field from the surface to the appropriate radar beam.
8. Most of us are taught that fresh snow has a typical density of 0.10. It actually has a range with 0.07 being a better value at many locations. Some of our products use 0.085.
9. We determine the power (beta) and coefficient (alpha) by minimizing a criterion function (absolute difference between gage measurements and radar estimates) as we increment beta from 1.0 to 3.0. Beta typically is near 2.0, with adjacent values giving little difference in the SAA results. For

locations in which the range of precipitation intensity is small, the procedure may not produce a minimum with hourly values. Switching to storm totals with the same data gives better results and the appropriate minimum at beta = 2.0. We have determined alpha and beta values for several geographically different sites.

The SAA output consists of accumulation files of snow water equivalent (SWE) and snow depth (SD) at a resolution of 1 km x 1 degree. Accumulation times are 1 hour, 3 hour, and storm total, with optional top-of-the-hour files for comparison with surface measurements. The files have the same format and are ended with a data line identifying the dates, times, and types of accumulations.

10. Hourly data generally produces much scatter when comparing radar and gage measurements of the snow accumulation.

11. Storm totals are generally within 0.20 inches of actual measurements and have much better correlation coefficients, as illustrated for Albany.

12. This past winter we have been using NIDS data to show snow accumulations for several time intervals from 1-hour to 24-hour totals. These products are available at http://www.usbr.gov/rsmg after clicking on NEXRAD Snow Algorithm Products. They may cease as the precipitation type changes to rain showers.

13. The merged products from the NIDS data show strong discontinuities between radar site pairs, indicating that Duluth and possibly Bismark are calibrated too low.

A mapping of the number of range bins having non-zero 24-hour precipitation over a 4.5 month period shows persistent ground clutter and some radial streaking. These may result from insufficient clutter suppression, a need for adjustments to the hybrid scan file, possible antenna tilt angle slippages, and/or from inadequate occultation files. We are adjusting the hybrid scan and occultation files by hand to minimize these irregularities. We are also working to identify virga at far range so that it is not considered in the accumulations.

A picture of a storm total accumulation from an intense lake effect snowstorm at Cleveland shows decreased amounts with range if range correction is not used. There is a further problem in this case with shallow storms being under the beam at far range.

Comments from the SAA users after field tests at Minneapolis, Cleveland, and Albany indicated general satisfaction with some needs for improvement. An unexpected result at Albany was that the SAA outperformed the PPS for cold stratiform rain below the bright band.

The Swiss have pointed out that there is a vertical gradient in radar reflectivity and precipitation rate in most storms. At far range the radar sees much weaker echoes because of elevation changes of the beam center and beam broadening. We have seen this at all sites. The present algorithm does not use the vertical gradient apart from a crude range correction equation. Using a climatological average gradient for range correction is superior to making no correction at all. This appears to be a technique for further improvement of the algorithm.

Future work should address some needed improvements, not anticipated in the original scope of work. However, the SAA is already robust and was greatly appreciated in the field tests. It now needs to be deployed elsewhere.

Note: Some of the overheads (numbered) are available at:
http://www.usbr.gov/rsmg/nexrad/snow_algor Others are available at http://www.usbr.gov/rsmg after clicking on NEXRAD Snow Algorithm Products.

Inquiries may be addressed to the investigators at the U.S. Bureau of Reclamation:

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3g. The Local Analysis and Prediction System (LAPS)

(Steve Albers, FSL)

The Local Analysis and Prediction System (LAPS) being integrated into AWIPS (versions 4.2 & 5.0), offers a useful platform for testing and operationally employing some of the multi-sensor precipitation integration concepts. We can either analyze precipitation within the LAPS grid, or use LAPS environmental data as input to external algorithms.

The LAPS precipitation accumulation analysis currently uses the vertical temperature profiles to specify the liquid equivalent to snow accumulation ratio. This coupled with a "known" Z-R gives us snow accumulation. This can perhaps be improved based the presentation given by Roy Rasmussen of NCAR.

As a future enhancement, we could modify the Z-R relationship based on the analyzed vertical temperature/humidity profiles, precipitable water, and precipitation type. In the longer term, we can improve the coupling of precipitation accumulation to the 3-D precipitation concentration field (grams/meter**3). This involves improving the fall velocity specification and possibly a relationship between Z and precip concentration to be applied three-dimensionally (Z-M).

We have also experimented with using vertical temp/rh profiles to modify the vertical reflectivity profile. This applies to an evaporation correction to the reflectivity profile beneath the radar horizon in the sub-cloud layer. Possibilities also exist here for bright-band correction.

Some of the above can be done with single level radar data, such as the hybrid reflectivity scan. We can do a better job if we have full volume reflectivity data integrated into AWIPS, even if the horizontal resolution is somewhat reduced.

We can also apply (approx hourly) gage corrections as well as fill radar gaps with satellite (NESDIS) precipitation products as they become available at FSL and on AWIPS in real-time.

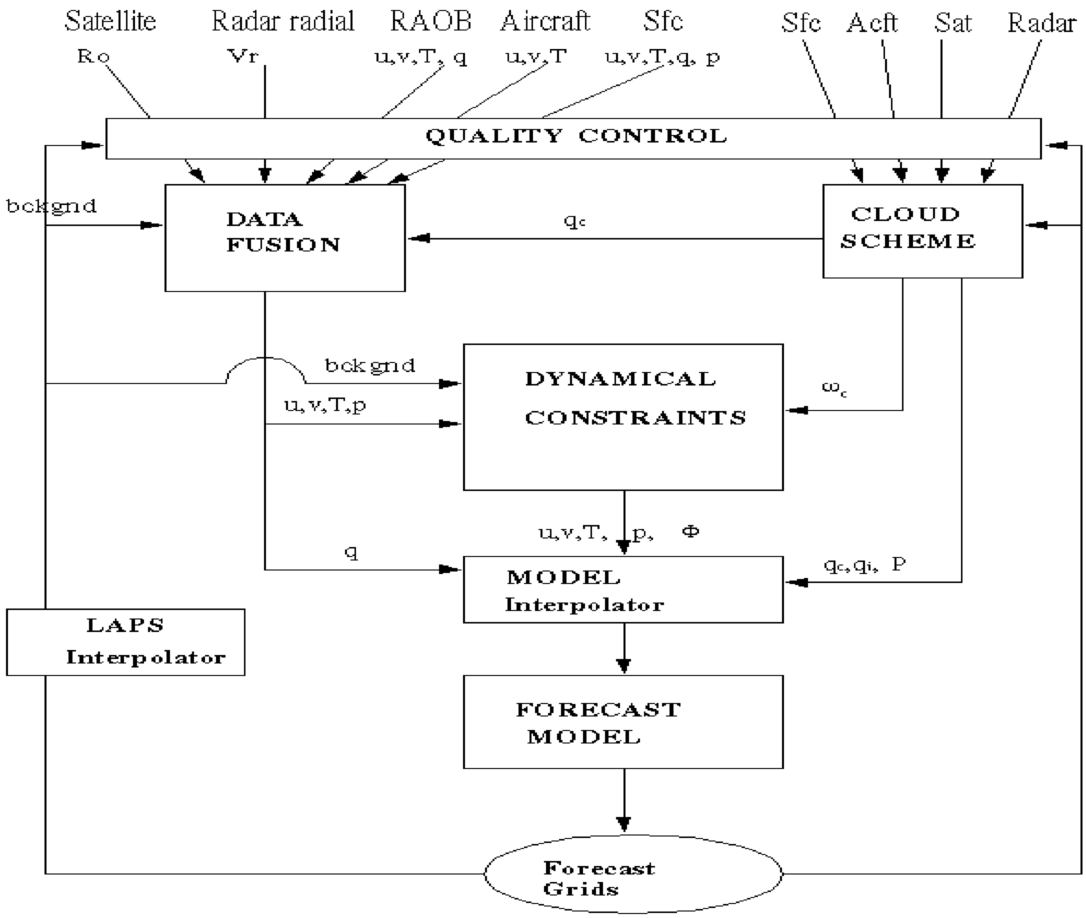
Details are updated in the following revised version of our Wx and Forecasting paper:
http://laps.fsl.noaa.gov/cgi/LAPB.pubs_topical.cgi

ALBERS S., J. MCGINLEY, D. BIRKENHEUER, and J. SMART 1996: The Local Analysis and Prediction System (LAPS): Analyses of clouds, precipitation, and temperature. Weather and Forecasting, 11, 273-287. Postscript(as published), Postscript(updated since publication).

You can click on either the published version or the version updated since publication.

There are also efforts at FSL to improve the initialization of the LAPS forecast models (e.g. SFM) with active clouds and precip. This entails a more robust integration of all data sources together with model microphysical and dynamical equations. The goal is to allow clouds and precipitation to appear correctly in the forecast model both at the initial time and for very short term forecasts using a 4DDA setup. This would in turn lead to a more accurate precipitation analysis. This is called LAPS-II and is illustrated in the attached GIF image.

LAPS II FLOW DIAGRAM



Session 4: Satellite-Based QPE

4a. Mapping the Course of Satellite Precipitation Estimates For Flash Floods into the 21st Century (Rod Scofield, NOAA/NESDIS/ORA/Hydrology Team)

This summary briefly describes a "road map" of satellite precipitation estimation (SPE) development (for heavy precipitation and flash floods) from the late1970s into the 21st century. For most of the past 20 years, the production of SPEs for flash floods has been a manual/ interactive process for alerting forecasters and hydrologists of the potential for heavy precipitation and flash floods. Precipitation estimates for flash floods are GOES driven products due to their high spatial and time resolution characteristics (GOES). As the 21st century approaches the challenge has been to automate (as much as possible) SPEs for flash flood application. Automation will allow an increase in SPE application from the already established "alert tool" (mentioned above) to infusion into: (a) the NWS/OH stage 3 product (gauge + WSR 88 D + satellite (planned)), (b) hydrological flow models that are run at local RFCs, and (c) cloud models that will in turn provide "physically-based" precipitation estimates.

The NOAA/NESDIS Satellite Analysis Branch (SAB) computes operational QPEs using the Interactive Flash Flood analyzer (IFFA) technique to provide real time SPEs to field forecasters and RFCs. SABs "SPEs" are sent out via AFOS and AWIPS. However, due to the manual/ interactive nature of the IFFA methodology, precipitation estimates cover limited areas for limited periods of time and can take a significant amount of time to produce. In order to improve the spatial and temporal coverage of SPEs, while improving timeliness, NESDIS/ORA has developed an automatic SPE algorithm called the Auto-Estimator. The experimental Auto- Estimator provides in real time the following precipitation information: (a) instantaneous rainfall, (b) average hourly rainfall rates, (c) 3 hourly rainfall accumulations, (d) 6 hourly accumulations, and (e) 24 hour accumulations. Currently, the experimental Auto Estimator uses 15 minute imagery (IFFA only uses 30 minute satellite pictures) and has the following characteristics: (a) precipitation intensities are based on a 10.7 micron cloud top temperature/ rainfall rate relationship, (b) a cloud growth factor (intensity adjustment), (c) an anvil gradient factor (location of active rain areas), (d) parallax correction (viewing angle adjustment), (e) topographic factor (adjust rainfall due to orographic uplift), (f) 15 minute WSR 88 D "DBz" data to help screen out rain/no rain areas. An equilibrium level temperature adjustment has just been inserted (August 1999) into the Auto-Estimator to help estimate rainfall from warm top convection; this new adjustment is being tested in real time by SAB and is available on the NOAA NESDIS Flash Flood Home Page: http://orbit35i.nesdis.noaa.gov/arad/ht/ff/
A technique that uses the visible as a locator of: (i) rain/no rain areas and (ii) intense rainfall cores are being tested off line in ORA.

In order to improve the accuracy of the Auto-Estimator and make this algorithm more robust, other channels from GOES (GOES has 5 imager channels) will be exploited for precipitation information. In a parallel effort to the Auto-Estimator, the 5 channel GOES Multi-Spectral Algorithm (GMSRA) has been developed in ORA; this GMSRA is being run in real time and being compared with the Auto-Estimator. Plans are to integrate the Auto-Estimator with the GMSRA by first initially inserting the rain/no rain discriminator of the GMSRA into the Auto-Estimator. Additional improvements will be to incorporate microwave from the POLES satellites. Particularly, over water and other remote areas (where WSR 88 D is not available), microwave precipitation estimates from SSM/I and AMSU will be used to continuously update GOES precipitation measurements both with respect to precipitation intensity and location. Updates will become quite frequent (every 2 or 3 hours) when both the SSM/I and AMSU passes are utilized. Microwave derived measurements are more physically/directly related to precipitation than those from GOES. However, microwave is only available on POLES platforms and are thus much less timely than GOES and have lower spatial resolutions. Where WSR 88D data is available, the SPE algorithm will continue to be used to not only delineate rain/no rain areas (mentioned above) but also, eventually, to calibrate and adjust the GOES estimates (both with respect to location and intensity).

The ultimate is to integrate the GOES with the SSM/I and AMSU, WSR 88D and in-situ rain gauge measurements to come up with a multi-spectral/multi-sensor algorithm for estimating precipitation from all types of precipitation systems (convective, tropical storms, stratiform, hybrids). Integrated precipitation data sets are a necessity for improving the prediction of stream/river flows and crests. Finally, artificial neural network techniques for estimating heavy convective rainfall have shown great promise. Our greatest hope is to have by the 2005 - 2010 time frame, microwave "flying" on operational geostationary platforms that cover the globe.

The NOAA/NESDIS ORA Flash Flood Home Page (mentioned above: http://orbit35i.nesdis.noaa.gov/arad/ht/ff) presents real time precipitation estimates from the experimental Auto-Estimator and GMSRA algorithms. This home page also includes experimental estimates for South America, Central America to Puerto Rico and the Lesser Antilles and Hawaii. Daily algorithm validation is also included to document the status of current algorithms and future improvements.

4b. Using Microwave Imagery to Generate a Tropical Rainfall Potential (TRaP) Product
(John Paquette, NESDIS)

Since 1992, the Satellite Analysis Branch (SAB) of the National Environmental Satellite, Data and Information Service (NESDIS) has experimentally used the operational Defense Meteorological Satellite Program's (DMSP) Special Sensor Microwave Imager (SSM/I) Rain Rate product to generate a maximum rainfall potential or Tropical Rainfall Potential (TRaP) for tropical cyclones expected to make landfall within 24 hours. In 1998, the SAB augmented the support by providing TRaP products for international users worldwide.

The experimental rainfall potential utilizes the operational DMSP SSM/I (15 km resolution) and now the NOAA Advanced Microwave Sounder Unit (AMSU) (45 km resolution; 15 km in the future) objective rain rates to produce an areal extent of rain and average rain rate through the tropical cyclone in its direction of motion.

In determining the TRaP for a tropical cyclone, the analyst follows a rainfall potential formula of (Ravg)(D)/(V). Ravg is the average rain rate (obtained from SSM/I or AMSU) through a line along the direction of motion of the cyclone; D is the distance of that line across the rain area of the storm in its direction of motion; and V is the actual speed of the tropical cyclone that can be measured using consecutive satellite images 3 to 6 hours apart. If significant changes in the intensity and/or speed are noted between the time of the microwave pass and the time the TRaP is produced, an adjustment of the TRaP can be made based on the latest half hourly geostationary satellite trends.

At the 2nd National QPE Workshop, April 13-15, 1999, SAB provided an example outlining the simple TRaP production technique for Hurricane "Georges" as it was heading for the Florida Panhandle. The example follows.

Using the 1500 UTC, September 27, 1998, DMSP SSM/I pass over Hurricane "Georges," the SAB analyst drew lines A and B through the digital rain rate (hundreds of an inch per hour) in the direction of the storm motion to obtain the highest average rain rate. Line A produced the highest value so it was used in the calculation of TRaP. Plugging in the parameters per the formula (Ravg)(D)/(V), the final TRaP is 31.3".

When a tropical cyclone is within 24 hours of landfall, SAB generates an experimental TRaP for inclusion to the operational Satellite Precipitation Estimate Messages (SPENES) relayed to the NWS field sites. Updates are provided based on the availability of polar orbiting passes, about two to three per day.

Spurred by the aftermath of Hurricane "Mitch," at the IHC in February 1999, representatives of the NWS' Tropical Prediction Center, Weather Forecast Offices, and River Forecast Centers, emphasized the importance on refocusing efforts to improve QPE for tropical cyclones. As an initial response to the issue, the TPC relayed an official requirement to SAB operations to produce experimental TRaP products when tropical cyclones are within 24 hours of landfall and located between 60W and 110W.

To further improve its hazards mitigation support for heavy rains from tropical cyclones, SAB is seeking assistance from the research community in TRaP verification, product automation, and improvements in accuracy. The objective is for NESDIS to collaborate on this initiative with the NWS including research offices such as HRD to ultimately validate the product for operational implementation.

To reflect the goals of the Workshop, the Satellite-Based Rainfall Estimation Group, Rod Scofield, Chairperson, introduced the action to pursue further development of the TRaP product to support NWS operations.

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4c. Ideas for Integration of Multi-Sensor Data for Heavy Rainfall Estimation
(Bob Rabin, Ken Howard, NSSL)

1. Introduction: Outline
Purpose: - develop QPE from all operational sensors
- Address problems of WSR-88Ds
2. Multi-Radar analysis
- Treating current deficiencies, exploratory techniques using satellite and other data
    - complex topography
    - mixed phase
    - bright band contamination deducing vertical reflectivity structure using S-band radars
    - chaff

-anomalous propagation
- Mosaic: account for altitude difference
    -range resolution
    -blockage

3. Combined radar-satellite method (Gourley)
    - applied to winter precipitation in Arizona
    - radar data rejected for blockage, bright bands
    - remaining data used to calibrate GOES-IR brightness temperatures
    - satellite used exclusively where radar data rejected
    - tested against rain gauges, positive results
4. Hourly accumulation from GOES "Autoestimator" (Gilberto Vicente, Rod Scofield)
    - tested against gauges in southern Wisconsin (D. Martin)
    - summer 98: underestimates in heavy rain
    - comparison with radar & gauges, Dallas flash flood event
    - utility of growth & gradient terms
5. Future plans
    -build data base
        -combine radar, satellite, lightning, gauge, and environmental data

Predictors:
- radar reflectivity at the lowest level
-height and depth of reflectivity measurement above ground
-cloud depth as inferred from satellite cloud top temperature and lower atmospheric RH
-precipitable water
-near surface convergence
-upslope flow deduced from terrain and surface winds
-freezing level

Predictand:
-hourly gauge data
- Visualization using VisAD
- Neuro-fuzzy statistical data modeling (Walmsley et al., 1999)
- Neuro network models (Marzban & Stumpf, 1996)
- Independent testing

6. Summary

Bob Rabin, Ken Howard and (*)Jian Zhang
NOAA/NSSL *- CIMMS, University of Oklahoma

4d. Overlay of Satellite and Radar Imagery for Precipitation Estimation
(Eric Hilgendorf, Research Associate CIRA)

The motivations behind researching satellite-radar overlays is the desire of the QPE community to integrate all observations. Our goal is to determine if these overlays have a use in QPE.

One of the methods the Cooperative Institute for Research in the Atmosphere (CIRA) is using to create the overlays is a Java Script method created by Tom Whittaker of SSEC-UW. This method uses .gif images of satellite and radar. A satellite gif is used as the background, and the radar gif is placed over the satellite gif. Tom's program allows the user to fade the radar image on and off the satellite background. The satellite image can be adjusted to remove the effects of parallax for a given height, but this adjustment must be done prior to making the overlay.

CIRA is currently creating overlays for analysis. Our next step is to assess the overlays for possible uses for QPE.

4e. Integration of Lightning Data to Improve Quantitative Precipitation Estimates

(Steven Goodman 04/23/99)

Observations from Space

Lightning activity provides a measure of the location, areal extent, duration, and intensity of deep convection. This capability is due to the sensitivity of cloud electrification processes to cloud updraft velocity and the formation of mixed-phase precipitation above the freezing level (Baker et al., 1995; Dye et al., 1986). Because of this physical coupling, it is possible to monitor convective storms and quantify some of their most important properties. Of paramount importance is the need to detect both intracloud (IC) and cloud-to-ground (CG) lightning. It is this total lightning that is related to the convective energy of the storm. Yet, reliable, robust, and quantifiable relationships between various storm parameters and lightning activity remain to be determined. At that point lightning data will be routinely used in multi-sensor algorithms and data assimilation.

With the TRMM Lightning Imaging Sensor (LIS), scientists can simultaneously observe relationships between total lightning activity and the structure and kinematics of storms worldwide. We can test our hypotheses that ice formation and updrafts play the controlling roles in cloud electrification, thus providing a unique approach for remotely sensing updraft intensity and ice phase precipitation. Early review of a few cases indicate that those oceanic storms that are not producing lightning (the majority) have significantly less mass above the freezing level than do continental thunderstorms. Lightning is unlikely unless reflectivity above the freezing level is greater than about 40 dBZ. Precipitation-sized ice is clearly indicated in those storms that are the lightning producers. Improved understanding of convective storms should lead to improved cloud parameterizations in process and forecast models.

NASA's proposed Lightning Mapping Sensor (LMS) will greatly extend the information obtained from the present low Earth orbiting (LEO) satellites. NASA's LIS and Optical Transient Detector (OTD) have been providing important observations of the distribution and variability of global lightning. However, because of the limited viewing time afforded by low Earth orbit, they are unable to provide detailed information on the onset and development of lightning activity and its relationship to the associated storm morphology, intensity, or evolution. The primary advantage of sensing lightning at geosynchronous altitudes is the ability to continuously monitor storms throughout their life cycle, from the first lightning flash to the last. This ability to continuously detect all lightning over large geographical areas, over both land and oceans, gives the proposed LMS instrument a unique perspective. At present continuous, total lightning measurements are only available at the TRMM validation sites in Florida and North Alabama (planned for Fall 1999) where locally operated Lightning Detection and Ranging (LDAR) lightning mapping systems are in operation. Good correlations among VIL, echo top, and LDAR lightning activity have been shown

(Weber et al., 1998), suggesting that lightning, radar, satellite, and even environmental data can be merged in new ways to better describe the structure of convective rain systems.

Data Fusion

A relevant example is the use of GOES IR data to infer convection. IR imagery has been widely used for studying the temporal variability, spatial patterns, and intensity of convection (Arkin and Ardanuy, 1989). In a recent study of the spatial-temporal variability of convective clouds over the tropical and sub-tropical Americas, it was found that techniques based on IR imagery alone overestimate the areal extent and lifetime of the actual convective systems because of the persistent duration of anvil cirrus clouds long after the underlying convection and rainfall has ended (Garreaud and Wallace, 1997).

In delineating convective-stratiform rain areas, Grecu et al. (1998) used spatial representations of the local CG flash density to improve (IR) satellite (only)-based rainfall estimates, and in their recent pilot study demonstrated an improvement over IR-only techniques. Buechler et al. (1994) explored various methods to augment satellite-based IR techniques with lightning observations of convective storms. Within the convective regions, the 15-minute CG lightning density was compared to the area average radar-estimated convective rainfall (defined by Z>35 dBZ). A regression between rainflux and flash density was then used to produce an estimate of the convective rainflux per flash. The lightning-derived rainflux would then be used to increase the limited dynamic range of the convective IR-only estimate.

Due to the connection between lightning activity and other convective parameters such as ice production and latent heat release, it is likely that the lightning data will be fused with traditional data sets and assimilated into mesoscale forecast models. Currently, the meteorological applications of lightning data have been prompted by its availability during times or at locations where traditional data sets were not available, such as over the oceans out of radar range or between overpasses of DMSP satellites that provide passive microwave measurements. Still in its infancy, the implementations of lightning data assimilation techniques show considerable promise.

Assimilation of Lightning Data into Mesoscale Models

Initial lightning assimilation methodologies have been successfully demonstrated by Alexander et al. (1998) using the NCAR/Penn State MM5 model, Jones and Macpherson (1997) using the U.K. Meteorological Office MES mesoscale model, and by Huo and Fiedler (1998) using the Advanced Regional Prediction System (ARPS) Data Assimilation System (ADAS). In the former, the method involves the calculation of proportionality between flash rates and convective *rain rates*, independently estimated using GOES IR and polar orbiting microwave sensors. The rainfall is then converted into grid point latent heating. Alexander et al demonstrated significant improvement in forecast central pressures when even limited CG lightning data was assimilated (http://neptune.gsfc.nasa.gov/microwave/lightning/modelling/index.html). In the latter, the method involves identifying the active lightning areas within the satellite VIS/IR imagery to delineate the location and depth of convective clouds within a field of high cloudiness. After the cloud cover analysis, the mixing ratio is adjusted to saturation within the cloud, and buoyancy is adjusted to support the added water substances. Both experiments simulated frontal systems moving across the Gulf of Mexico, through Florida, and up the East Coast of the U.S. In the Jones and Macpherson simulations, lightning observations were used to estimate the areas of convective rainfall within the model domain over the ocean that extended beyond the range limits of the U.K. radar network. A latent heat nudging scheme was used to assimilate the rainfall into the model.

Lightning-Rainfall Relationships

Given the tight coupling between lightning and updraft strength it is reasonable to expect some interesting and useful relationships between total lightning and deep convective rainfall that was generated by the ice process. We know that warm phase precipitation is not typically associated with lightning; therefore, any useful lightning/rainfall relationships can only be applied to glaciated convection.

Our current level of understanding of ***L-R*** relationships is incomplete. Petersen and Rutledge (1996) found a strong regime dependency (e.g., oceanic, tropical, extra-tropical, arid, low- or high-shear environments). Their study measured only CG lightning associated with convective rainfall. However, when strong updrafts grow ice, lightning is produced, thus the lightning-ice relationship should be regime independent. More detailed measurements of IC and CG lightning will allow us to test this hypothesis, and to better understand the process physics involved. At the very least, the lightning will help constrain IR retrieval techniques by clearly delineating the updraft region, its strength and duration, and will improve short-range precipitation forecasts by validating the convective parameterizations in the mesoscale models. More probably, the lightning data will enhance existing capabilities by improving the quantitative estimate of ice phase precipitation, and by improving convective-stratiform classification and identifying warm phase precipitation by its lack of lightning. Recent evidence from TRMM supports the concept that ***L-R*** is not regime dependent but rather convection dependent. When ice is inferred from the TRMM Precipitation Radar or TRMM microwave Imager (TMI), lightning is detected. When the cloud mass is below the freezing level there is no lightning.

Potential Lightning Contributions to Improve QPE

From the prior discussion we may conclude that lightning observations may offer the following additional information to improve Quantitative Precipitation Estimates (QPE):

Identify trends of storm growth and decay

Identify potentially severe and hazardous weather

Determine the existence/separation of convective and stratiform areas

Provide observations in data sparse regions (gap filling for radars in mountainous terrain and incomplete radar mosaics, oceanic areas and the Gulf of Mexico)

Provides new opportunities for data assimilation and evaluation of cloud parameterizations

Identify appropriate (tropical vs default) and adaptive Z-R relations under the radar umbrella based on the presence or absence of lightning combined with the meteorological environment and radar observables

The blending, fusion, and assimilation of lightning, radar, satellite, and environmental data and its availability within AWIPS will provide many opportunities to test and evaluate the added utility of lightning observations. The NLDN CG data will be available nationwide. The LDAR data will be available within selected local areas where its added utility can be evaluated. TRMM data over the data sparse oceanic regions is already being used at NCEP, but the suite of instruments should be more widely used to better characterize the structure of storm systems and NEXRAD rainfall estimates.

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4f. Recent Results in Satellite Precipitation Estimation using Geosynchronous IR and Low-Orbit Microwave Data in Combination (R. Adler, NASA Goddard Space Flight Center)

Results are described using low-orbit microwave estimates of precipitation to calibrate or adjust rainfall estimates using geosynchronous IR observations. This adjustment procedure is applied in different ways to time and space scales varying from near global and monthly estimates to instantaneous estimates. Possible use of TRMM observations and the use of lightning information to improve geo IR estimates are discussed.

The Global Precipitation Climatology Project (GPCP) monthly, 2.5 degree precipitation analysis is described. This standard, community product is a merger of low-orbit microwave, geo-IR, TOVS and gauge-based estimates. The philosophy of this analysis is to use the better estimates to adjust the more frequent to produce a product with low bias and good sampling. Over land the gauge information is used as much as possible to set the bias, while over ocean the microwave estimates lead the way.

An example of TRMM Precipitation Radar (PR) data is shown. The use of TRMM estimates should improve global merged data sets and the TRMM radar data could be used to investigate the calibration of surface-based radars.

Moving to smaller scales a technique to produce a one degree, daily, global analysis starting in January 1997 is described, again using microwave estimates to set the Tb threshold and conditional rainrate as a function of grid location. These relations are then applied to the geo-IR data and rescaled TOVS-based estimates in polar regions. This first version of the technique will be improved by reinserting the microwave estimates in the time and locations where available to produce a truly merged microwave/IR product.

For instantaneous estimates a modification of the Convective Stratiform Technique (CST) is used with GOES data over Amazonia, with the parameters of the IR technique set by the microwave-based estimates using a colocated data set. It is suggested that a similar procedure could be used with ground-based radar estimates being used to calibrate the IR estimates over the U.S.

A possible use of lightning data to identify convective cores and help determine rainrates is described as a way to improve geo-IR rain estimates. Examples are shown and a preliminary statistical analysis indicates that the lightning data should be of value to improve IR rain estimation.

In closing, a future satellite program, the Global Precipitation Mission (GPM) is described which will have a core satellite, a TRMM follow-on in a higher (70 degree) inclination together with a constellation of small, inexpensive satellites with passive microwave sensors to provide much better sampling of the microwave observations. Approximate planned lunch date of such a system, if funded, is 2007.

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Session 5: QPE in Data Sparse Complex Terrain

5a. Mountain Mapper
(Gregg Rishel, WR Deputy Chief HSD)

Mountain Mapper is a suite of software tools designed to estimate hydrometeorological parameters in complex terrain utilizing PRISM data. The suite was developed in the Colorado River Forecast Center, principally by Craig Peterson and Art Hinkle. The suite has been adopted by for operational use throughout the Western Region.

PRISM stands for Parameter-elevation Regressions on Independent Slopes Model. The PRISM data set is a set of estimated gridded climatic parameters which have been generated using point climatological and digital elevation model (DEM) data. The technique utilizes orographic parameters such as slope, aspect, and elevation to estimate climatic parameters in complex terrain. PRISM data is available in annual and monthly average formats. The grid utilized in PRISM is 4km by 4km.

Mountain Mapper is comprised of three applications programs. Specify is the program that provides the tool for spatially distributing point hydrometeorological data, i.e. QPF, that has been entered into the system. Daily-QC is the tool that provides a mechanism for quality controlling and spatially distributing observed hydrometeorological data. The final tool is Verify, that provides a means of comparing entered and observed data, i.e. compare QPF with observed rainfall.

The process Mountain Mapper uses to convert point data to a grid and ultimately a mean areal estimate is rather simplistic. The tools use an HRAP grid of 4km by 4km which matches the grid used in PRISM. The first step in the conversion process involves the creation of a ratio between each point observation or entered data ($DATA_x$) with the PRISM monthly normal (N_x) for that location for the appropriate month. The formula for this ration is:

$$RATIO = \frac{DATA_x}{N_x}$$

If we assume that the ratios are constant across the grid, then:

$$DATA_x = N_x \frac{DATA_1}{N_1}$$

However, this assumption is not valid for actual events. The temporal and spatial characteristics of any precipitation event will not likely follow the climatic normals. To improve the estimated data on the grids two procedures are employed. The first is that Mountain Mapper uses the five closest observed or entered data points to estimate the value of an unknown grid point. The second is that a commonly used 1/distance^2 weighting fact is applied to all of the grid point ratios. The final equation for calculating an unknown data value is:

$$DATA_x = \frac{\left[N_x \frac{DATA_1}{N_1}\left(\frac{1}{d_1^2}\right)\right] + \left[N_x \frac{DATA_2}{N_2}\left(\frac{1}{d_2^2}\right)\right] + \left[N_x \frac{DATA_3}{N_3}\left(\frac{1}{d_3^2}\right)\right] + \left[N_x \frac{DATA_4}{N_4}\left(\frac{1}{d_4^2}\right)\right] + \left[N_x \frac{DATA_5}{N_5}\left(\frac{1}{d_5^2}\right)\right]}{\frac{1}{d_1^2} + \frac{1}{d_2^2} + \frac{1}{d_3^2} + \frac{1}{d_4^2} + \frac{1}{d_5^2}}$$

A mean areal estimation of the hydrometeorological parameter in question may be created simply by performing an arithmetical average on the values of the grid points with the basin. As an example a mean areal precipitation would be calculated using the following equation.

$$MAP = \frac{\text{Sum of Values for Grid Points in Basin}}{\text{Number of Grid Points Within the Basin}}$$

Mountain Mapper has proven to be an operationally effective way of estimating hydrometeorological parameters in the complex terrain of the western United States. The technique is viewed as a step in providing such estimates and future develop should improve its usefulness. It is hoped that the technique will be incorporated into a Build of AWIPS in the near future so that the NWS operational forecasters can utilize it more effectively.

5b. Atmospheric Models (Simulation and Prediction)
(Michael E. Baldwin NCEP/EMC/GSC)

Throughout the history of NWP, as computing power has increased, operational and research models have obtained increased resolution, accuracy, and sophistication. Although operational NWP models have demonstrated significant improvement in skill of precipitation forecasts (for example, Mesinger 1996, BAMS), there is still much effort to be made before short term quantitative precipitation forecasts (QPF) can be considered useful as quantitative precipitation estimates (QPE). However, atmospheric models can be considered excellent "integrators" of different types of data when used as part of a variational data assimilation system. This may be especially true over data sparse, mountainous terrain.

The existing network of real-time, hourly gage observations is not sufficient to accurately estimate the spatial coverage and intensity of rainfall over most of the U.S., particularly in mountainous. In addition, well known problems with radar and satellite precipitation estimates (beam blockage, overshoot, warm cloud tops, etc.) prevent these remote sensing instruments from solving the QPE problem on their own. Past experience in data assimilation has shown that attempting to use a single observing platform to "retrieve" information on the full state of the atmosphere can only provide a limited amount of success. Other information, which may be obtained from other observing systems and numerical models, is required. An atmospheric model will have information, to some degree of accuracy, on the dynamical and physical processes that affect precipitation. It can also provide information related to the "problem areas" of the remote sensing instruments, such as the existence of melting layers and sub-cloud evaporation. The greatest benefit will be obtained when all possible sources of information are combined in an optimal manner. The theoretical basis for the optimal combination of a prediction model and observed data is well posed and has been researched by many different disciplines.

There are several components of a data assimilation system that need to be obtained before useful information can be provided. Perhaps the most important component is the atmospheric prediction model. The NWP model must contain enough resolution and sophistication in the dynamics and physics such that processes related to precipitation can be captured, to a satisfactory degree of accuracy. This requirement may not be too far from being realized, for example the operational RUC-2 currently contains a sophisticated cloud physics package that predicts 3-D mixing ratios of water vapor, cloud water, ice, rain water, snow, and graupel along with number concentration for ice particles. For the future, a large research and development effort is currently underway on the WRF (Weather Research and Forecast) model, which is intended to become the "unified" model used both by the NWS and the research community. It is expected that the WRF will be the "state of the art" NWP model and contain the best available physical parameterization and dynamical schemes. In addition, EMC expects to be running an operational mesoscale model at approximately 10km resolution over a regional domain in 2000-01 on the recently purchased Class VIII IBM-SP computer, and perhaps at 10km over all of North America on the Class IX computer expected to be acquired in FY 02/03. 10km horizontal resolution may not be fine enough to capture all convective scale processes important for flash flooding, but this gives an indication of the progress that is planned in the 5 year time frame.

The other major components of the data assimilation system that need to be built are so-called "forward models", which relate variables that the model *predicts* (cloud, moisture, temperature, wind) to parameters that are *observable* (reflectivity, radiances, radial velocities). These "models" are used to produce "first guess" fields from the model and will need to be quite complex. The reflectivity model will have to be a function of temperature, topography, cloud, and precipitation variables so it can mimic what the actual sensors are observing, for example, estimating the radar beam elevation and creating a first guess bright band if a melting layer exists there. Some of this work is ongoing, the operational Global Data Assimilation System (GDAS) at EMC currently assimilates raw satellite radiance data, so the forward model for satellite radiances for the global model has been created. EMC plans to add assimilation of radiances to the Eta Data Assimilation System (EDAS) in the near future.

Once the data assimilation system has been built, it will operate as follows:

- A short term NWP forecast will provide the first guess.
- Forward models turn these variables into first guess fields of reflectivity, radiances, doppler radial winds, etc.
- These fields are compared to observed fields and increments are produced.
- The forward models are transposed so that increments of the observed variables (reflectivities, radiances) are mapped into increments of the model variables (clouds, temperature, etc.).
- These increments are applied to the original first guess fields, weighted based upon the error characteristics of the observing instruments and the model.
- This produces initial conditions for a new forecast, the QPF from that short term forecast can be used as QPE.

This method will take advantage of all available sources of data, the modeled dynamics and physically processes of the atmosphere, and error properties of the model and each observing system to produce the best possible estimate of the atmospheric state, including quantitative precipitation. This technique can, in theory, also be expanded to provide estimates of the analysis error, which is an important piece of information not currently available to users of QPE products.

Session 6: Integrated Systems, Products and Training

6a. WFO Hydrologic Forecast System (WHFS) and Flash Flood Guidance (FFG)

(Roger Pierce, OH)

WHFS WFO Hydrologic Forecast System

WHFS project leader in the Office of Hydrology, Hydrologic Research Lab is Mr. Jon Roe. The program leader and coordinator of a team of individuals for WHFS is Mr. Jeff Zimmerman. This program of support is expect to continue on into the future. In addition to question and answer support, this group also gathers information concerning enhancements to the system from the field. These issues are collected and ranked base on the field's requests and the difficulty in implementation. All of the requests from the field were presented for possible inclusion to AWIPS Build 5. The final ranking and development decisions will take place in August 1999. It is very clear that WHFS must be migrated into the D2D environment as quickly as possible and every effort will be made to get Hydroview and River Pro tasks into D2D completed. Other planned enhancements include development of the Site Specific model for use at WFO's and the concepts involving the originally described Area Wide Prediction System into what is now called Flash Flood Monitoring and Prediction (FFMP). FFMP will be designed around concepts related to System for Convection Analysis and Nowcasting (SCAN).

Flash Flood Guidance (FFG)

FFG is going to be modernized in the next year. The FFG is going to be GIS based and at HRAP grid resolution. The Sacramento Soil Moisture Accounting Model or the Continuous API model are going to be used to generate anticedent soil conditions. The GIS information will provide information to calculate a Threshold Runoff Value to be used in association with these soil conditions to provide a FFG value. The current plans are to have the ThreshR software available at the RFC's sometime around the March 2000 time period. The RFC's will begin implementation as quickly as they can. The expected time would be summer or fall 2000 for most RFC areas to be covered.

6b. Areal Mean Basin Estimated Rainfall (AMBER) Program

(Robert Davis, Pittsburgh NWSFO)

Five flash flood case studies were presented using the AMBER playback software. WSR-88D archive II data was used to generate radar rainfall estimates on a one degree by 1 kilometer grid. The rainfall data was mapped by AMBER into the watersheds that produced flash flooding in each of the five cases.

The first case study was the flash flood in Dallas, Texas, on May 5, 1995. Heavy rainfall approaching 5 inches in one hour in small watersheds of 4-8 mi^2 resulted in 16 fatalities. Using the WSR-88D tropical Z/R rainfall rate, AMBER detected the heavy rainfall almost 30 minutes before flooding began. AMBER indicated that 4 inches of rain fell in about 40 minutes in the Turtle Creek watershed.

AMBER produced excellent results in the second case study, a flash flood in Buffalo Creek, Colorado on July 12, 1996. Using the default WSR-88D Z/R rainfall rate, AMBER detected over

3 inches of rain in about one hour in Sand Draw and Spring Gulch, two small tributaries of Buffalo Creek. These tributaries are contained within a 9 mi^2 area of Buffalo Creek that was stripped of vegetation by a wildfire prior to the flood. AMBER detected the heavy rainfall about 45 minutes before flooding began.

The third AMBER case study was the Fort Collins, Colorado flash flood of July 29, 1997. Using the tropical Z/R rainfall rate AMBER indicated that 8-9 inches of rain fell over the 11 mi2 area of Spring Creek over a 4 hour time period. AMBER indicated three increasingly heavy bursts of rainfall occurred, first at 0045Z, a second at 0200Z and the heaviest burst from 245-345Z. AMBER first indicated that flooding was likely around 0200Z, almost three hours before fatalities occurred.

Flash Flooding in Zion National Park on July 27, 1998 was the fourth AMBER case study. A 35 mi^2 area of the North Fork of the Virgin River, was doused with almost two inches of rainfall in about one hour. AMBER indicated the initial burst of heavy rainfall around 2000Z, almost two hours before flooding was observed in the "Narrows" of Zion National Park. The standard Z/R rate of the WSR-88D produced excellent results.

The fifth AMBER case study was the Kansas City, Missouri flash flood of October 4, 1998. Using the default WSR-88D Z/R rate, AMBER indicated that about 2.5 inches of rain fell in about one hour across the Brush Creek and Turkey Creek watersheds in the Kansas City urban area. In fact over 5 inches of rainfall was observed, showing that the WSR-88D tropical Z/R rate needed to be used to provide accurate results for this case. Using the tropical Z/R rate, AMBER estimated that about 5 inches of rain fell in about one hour.

AMBER has been used in real time in the Pittsburgh National Weather Service Forecast Office (NWSFO) since the summer of 1996. A case study of the Ohio flash floods of June 26-28, 1998 was presented to show how AMBER can be used as guidance for the issuance of flash flood warnings. From 800 PM EDT on June 26, 1998 to Midnight EDT on June 29, 1998, the Pittsburgh NWSFO issued 88 flash flood warnings with an average lead time of 5 hours. Over 88% of the flash flood warnings verified.

One the first night of this event, AMBER showed that the Wakatomika Creek (226 mi^2) received Average Basin Rainfall (ABR) of 6.8 inches in about 6 hours. The stream gage at Frazeysburg, on the Wakatomika, rose from 6 inches to 11 feet from midnight until 700 AM EDT. The early alert by AMBER at between 200-300 AM EDT, allowed a warning to be issued with about 4 hours of lead time.

Over the 60 hours of heavy rainfall, AMBER indicated that the Mean Areal Precipitation Area (MAP) upstream from Cambridge, Ohio received 7.78 inches of rainfall. Record river flooding at Cambridge (13 feet above flood stage) resulted from this widespread rainfall. The observed MAP rainfall determined from rain gages after the event indicated that 7.61 inches of rainfall occurred, very close to the real time AMBER estimate of 7.78 inches.

These case studies indicate that AMBER can be as a very effective tool in providing guidance to the flash flood forecaster. AMBER provides basin specific rainfall (ABR) for direct comparison with Flash Flood Guidance (FFG) to determine the potential for, and severity of, flash flooding. The ABR rate information, provide by AMBER every 5 minutes, alerts the forecaster to watersheds where flooding may occur before flooding begins. This early alert to the forecaster can greatly increase warning lead time. The AMBER rainfall database allows the forecaster to determine how much rainfall has fallen in a specific stream watershed over the past 72 hours. This rainfall history of each watershed allows the forecaster to determine the relative validity of FFG. AMBER provides the forecaster with a direct connection between rainfall and the watershed impacted by that rainfall. The forecaster can use this information to specify within the warning, streams, roads, or urban areas that may be impacted by the flash flooding. AMBER provides a wealth of information to the flash flood forecaster that is simply not available from any other source.

6c. Development of a Physically-based Flash Flood Index

(Baxter Vieux, University of Oklahoma & Kenneth Howard/Ami Arthur, NSSL)

1. Introduction

Floods are historically the most costly of all weather-related hazards in the US. On average, over the past 30 years, 139 lives are lost each year due to flooding, with the death toll in recent years rising to over 200 per year. More than 50% of all presidential declared disasters are due to floods. In the last ten years, damages/costs have been estimated by NOAA (1999) to exceed $170 billion not considering losses in productivity. While average annual deaths due to tornadoes have decreased from a high in 1930-39 of 194.5; 40-49 178.6; 50-59 141.9; 60-69 194.5; 70-79 99.8; 80-89 52.2; to 28.6 in 1990-96 (USA TODAY, 1997), those due to flooding have actually increased to over 200 per year in the US over recent years suggesting the need for improved flood warning systems.

The overall goal of this project is to develop a Flash Flood Index (FFI) for use by the National Weather Service in an operational setting. Flood or flash flooding results from intense, though short duration, storm events. The FFI would be validated on geographically diverse basins using a distributed-parameter physically-based flash flood model (FFM) and measure stream discharge. The size of basin is smaller in area than that forecast by the already established NWS River Forecast Centers. The target subbasins are on the order of 10 to several 100 km2. Such areas are the responsibility of the weather forecaster at the NWS Forecast Office, though current practice is to issue flood warnings for an area such as a county. The WSR-88D radar has improved considerably the detection and warning of severe storms, e.g., tornadic outbreak in Oklahoma City, May 3, 1999. The WSR-88D processing system has built-in detection for features related to tornadoes and precursor circulation. However, at present, no such detection tool exists for flash flood prediction except generalized flash flood guidance threshold values based on antecedent rainfall.

1.1. Background

Though strict definitions between floods and flash floods are difficult, and no clear distinction exists; flash floods are usually considered to occur during 1-6 hours since the onset of rainfall or due to a dam break. Since the magnitude of the flood response in a river basin depends on the combination of atmospheric phenomena, intense rainfall, and terrestrial features (soil type, topography, vegetation and antecedent soil moisture), it is difficult to say which physical domain, atmospheric or terrestrial, dominates. From a meteorological perspective, certain atmospheric conditions must be present for intense, flood producing rainfall to occur, most notably, moisture, lifting mechanism, and potential for deep convection (Doswell et al., 1998). While some storms produce flash floods, others, with just as heavy or even greater rainfall totals, do not. Senesi et al. (1996) compared two storms of nearly equal magnitude that occurred within days of each other in the same region of central France. Because of channel configuration, the Vaison-La-Romaine river flooded causing extensive damage and loss of life. Komusôu et al. (1998) investigated an outbreak of flash flooding on the Aegean coastal town of Izmir, Turkey, which resulted in $50 million in damages and 61 deaths. While the pressure and moisture patterns were characteristic of synoptic type flash floods identified by Maddox et al. (1980), non-meteorological factors of topography, geomorphology (insufficient channel capacity), and landuse (flood plain encroachment) contributed to the severity of the flood impacts. Georgakakos (1986) observed that flash flood studies must consider both the meteorological factors responsible for the flood producing rainfall as well as the hydrologic or terrestrial features that transform intense rainfall into a flood. Though probabilistic in nature, he proposed a real-time flash flood warning system recognizing the importance of coupling the hydrological and meteorological phenomena for the nationwide prediction of flash floods. It should be noted that computational limitations to running numerical models in real-time and improved radar estimates of precipitation offer more sophistication than was possible than whenfirst proposed in 1986.

The Hydrometeorological Information Working Group (HIWG) was established by the NWS and NOAA in 1990 with specific charge to: 1) "establish and update operational requirements...in support of river and flash flood forecasting, and 2) define the roles, responsibilities, and relationships of the components of the End-to-End Forecast Process for Quantitative Precipitation Information (QPI)." This effort is implemented in the system known as the Area Wide Hydrologic Prediction System (AWIPS), which is the cornerstone of modernization of the NWS (NOAA, 1999b). WDSS-II is planned to become a component of AWIPS. Initial testing of the OUFEA model has begun for the Rappahannock basin which is the responsibility of the Sterling VA NWS WFO as a part of the action plan published in "The Modernized End-to-End Forecast Process for Quantitative Precipitation Information: Hydrometeorological Requirements, Scientific Issues, and Service Concepts." (NOAA, 1999b). The proposed FFI and WDSS-II development were presented at the 2nd National Quantitative Precipitation Estimation (QPE) Workshop, April 13-15, 1999, Boulder CO. This agency workshop was designed to bring together NOAA and NWS personnel to identify needed research for improved services delivered by the NWS. The FFI and WDSS-II implementation were identified as action items for the AWIPS system improvements (NOAA, 1999c). Institutional foundations are in place to implement an improved FFI.

To take advantage of recent technological advancements, the effort proposed herein is supported by an existing physical and intellectual infrastructure built on institutional relationships between the NWS offices, NOAA National Severe Storms Laboratory (NSSL), the Salt River Project (SRP), and the University of Oklahoma (OU). A national need exists for an FFI that can be applied over small basin areas and is automatic in the sense of using the WSR-88D precipitation estimates and terrestrial features in a relatively unattended mode in the operational settings typically found in NWS Weather Forecast Offices (NWS WFO). This gives rise to needed research to test certain hydrologic and meteorological assumptions in the FFI development.

1.2. Objectives

The overall goal of this proposed project is to develop and implement tools and algorithms that in real time can automatically identify individual basins at risk to flood or flash flooding resulting from intense, though short duration, storm events. The development process and product application builds upon the existing hardware and communications infrastructure and WSR-88D data streams; on-going efforts to develop distributed-parameter physically-based simulation of river basin response; and lay the ground work for improved flood forecasting taking advantage of the WSR-88D data stream. Specific objectives are: 1) Delineate watershed sub-basins for each radar umbrella covering the subject watersheds, 2) Extract, refine and expand precipitation input from archive level-2 tapes, 3) Setup FFM topographic, soils, and landuse/cover, and stream flow datasets for basins, 4) Develop initial FFI functional form modifying as needed and re-evaluating, 5) Compare FFI and FFM skill indices for the observed stream flow records, and 6) Facilitate integration of the FFI into WDSS-II for the NWS AWIPS system. The methodology for accomplishing these objectives is described below.

2. Proposed Methodology

The project will progress in a series of tasks linked to each of the above objectives. Research will be conducted jointly by OU in collaboration with the NOAA-National Severe Storms Laboratory and NWS Forecast Offices in Phoenix AZ, Norman OK and Sterling VA. NSSL personnel have parallel or complementary responsibilities identified for each task. The skill or ability of the FFI to predict which basins are likely to flood will be compared against the observed and simulated stream discharge. The FFM will be based on ongoing research at OU to develop distributed-parameter simulation of river basins using the WSR-88D radar. The skill index of the FFM will be determined for the same basins. Then the skill indices will be compared to see if the FFI is at least as good as the FFM at ranking basin response to a series of storm events. Testing, and modification as necessary, will determine if the essential characteristics, viz., physical processes, are sufficiently well represented by the FFI. The resulting system and validated FFI technique is expected to serve as a blue print for nationwide implementation by the NWS.

Efforts at NSSL to couple the OUFEA model with an operational WSR-88D have been underway since 1998 (cf. Vieux et al., 1998a). This model has already been calibrated and validated for 12 storms in the Illinois River basin (Jones et al., 1998). Current efforts at NSSL by Vieux, Arthur, and Howard are underway to calibrate for 12 more storms in the Blue River basin. These validated results will be used to determine the skill with which the FFM can rank order storms events by peak discharge rate.

The proposed research addresses a critical national need through the development of a validated FFI within the AMBER framework (described below). The FFM will be used to provide a physically-based, hydrologic model to validate the FFI. This serves as a benchmark for evaluating the FFI where basins have monitored stream flow. Plans are underway to delineate basins for every radar umbrella in the US for the purposes of establishing flood warnings on a watershed basis rather than by county. A large part of this work was initiated through work by NSSL in concert with NWS personnel. Surprisingly, without AMBER, no basin-estimates of precipitation are possible within the currently configured WSR-88D processing system. AMBER is the key to providing flood warnings by basin rather than on a county-wide basis as is currently practiced within the NWS system.

The AMBER program was developed by Robert Davis at the Pittsburgh, PA NWS WFO to assist in flash flood warning decisions. Over a range of hydrologic and temporal scales, AMBER accumulates rainfall based on the WSR-88D Digital Hybrid Scan Reflectivity (DHR) product. The accumulations for each 1-degree by 1-km bin in a radar coverage area are used to calculate an area weighted average accumulation. This provides the precipitation input for the FFI.

Currently, the AMBER output display developed at NSSL includes three components. The first is a geographic display consisting of maps of the first four categories of basins mentioned above, color coded according to flash flood potential. A yellow alert indicates an ABR value that is 80% of the threshold guidance value, and a red alert indicates an ABR value that is greater than or equal to the threshold guidance value. Streams, county lines, and state lines can also be overlayed in the geographic display. The second component of the AMBER display is a table containing the output ratios of ABR to threshold guidance value for a range of time intervals. Information in the table is color coded with the same yellow and red scheme used in the geographic display to indicate flash flood potential. The third display component is a plot of the ABR rate and the cumulative ABR versus time. This scheme has proven to be advantageous for flash flood warnings in the Pittsburgh, PA NWSFO through the efforts described in Davis (1998). The work planned herein seeks to extend the tools available to forecasters to a more sophisticated one that accounts for precipitation and terrestrial factors that play into the flash flood generation mechanisms.

To establish an AMBER data set, basins are delineated using the ArcView GIS with the Spatial Analyst Extension. Basins have been delineated for several NWSFOs using the USGS 1:250,000-scale digital elevation models (DEMs) with a 3 arc-second grid cell resolution. The 1-degree by 1-degree DEM sections are merged to produce one DEM for the area of interest (generally a radar coverage area). Optionally, a digital map containing rivers and streams such as the River Reach Files developed by the EPA may be used to improve the quality of the basin delineation. These delineated basins are edited and combined into the various basin categories used in AMBER. Finally, each 1-degree by 1-km radar bin in the radar coverage area is mapped to the basins in each category, and this information is stored in the AMBER files. Additional information for each basin is also gathered and stored in these files, including each stream or basin name, latitude and longitude coordinates of each outflow point, and the corresponding counties and their FIPS and zone codes. The project staff at NSSL are developing a nationwide standard for delineation and are currently delineating or have delineated the radar coverages for the study areas.

AMBER will provide the framework through which to apply the FFI to the subject watersheds. The AMBER basin delineation process will be extended to provide factors affecting flash floods that depend on topography, landuse and vegetative cover, and soils. During real-time testing the AMBER basins will be used to sample the precipitation processing output from the radar via WDSS. It is envisioned that the AMBER basin delineations will become a part of a nationwide mosaic of flood prone basins showing flood risk. Besides improving the NWS forecasters set of tools, benefits are expected to include better planning and logistics for flood relief provided by the Red Cross and FEMA, and state emergency management agencies.

The AMBER, WDSS, and OUFEA data and systems will be completed for the subject watersheds. The Rappahnock in the Eastern US (Virginia), the Blue and Illinois River basins in the Midwest, and the Indian Wash Watershed in the West will be used to compare the skill of the FFI versus the skill of the FFM in reproducing the rank ordering of obseved peak discharges. Though not representative of all climatological and physiographic regions of the US, the subject basins are typical of the Eastern, Western, and Midwestern regions of the US.

Recommendations and Summary

1. Basin-oriented flood warnings require precipitation from multiple sensors (WSR-88D, satellite, rain gage) estimated for each basin. AMBER is key for operationally obtaining these estimates. AMBER delineated basins are derived from readily available digital elevation data (e.g. 3-arc second DEM from USGS or NIMA). The basin size should be selected according to a consistent set of standards that would permit a mosaic of flood prone basins so that comparisons are valid across regions and radar umbrellas. Considerations for developing the AMBER basin size include:

1.1. Basin size depends on geomorphology of the drainage network, climate, geology, vegetation and other controlling factors. For example, in the Western Intermountain region where a steeply-sloped basin discharges to an alluvial fan, the point of interest may be the top of the alluvial fan.

1.2. Basin delineations should result in a discharge point located at a 'hazard point' such as a school, hospital, residential development, or bridge.

1.3. Basin size affects the statistical distribution of rainfall rates, and thus, the mean basin rainfall. The spatial correlation distance of the rainfall compared to the size of the basin affects the mean value. Research is needed to identify the effect of basin size mean values for a range of storm types and climatic region.

1.4. Time of concentration is the time it takes runoff to travel from that part of the watershed most remote from the outlet. A specified climatological return period and duration could be used to set the size of basin. For example, the 15 minute duration, 2 year return interval could be used to define the time of concentration together with slope, hydraulic roughness, and drainage length. This would enforce a basin size based on how fast the basin responds to a rain storm of specified risk.

1.5. From consideration of the number of radar bins sampled per basin, a minimum basin size can be set. For example, if one sets a criteria of having 4 radar bins over any particular basin out to 230km, then a minimum size of 16 km2 would be indicated.

2. Opportunity exists to make improved flash flood warnings given AMBER delineations on a nationwide mosaic of basins. This would form the basis for a Flood Prediction Center similar to and in conjunction with the Storm Prediction Center.

2.1. Flash Flood Index (FFI)-Forecasters need an automated system that tracks the potential for flash flood by basin rather than the CWA or HAS. The would provide an automated tracking system to help indicate basins prone to flash flooding. The FFI is composed of both static factors (terrain, soils, and vegetation) and dynamic factors (precipitation rate and accumulation). The static factors FFIs could be used to rank basins that are particularly prone to flooding in response to any heavy rain event. The dynamic factors FFId would then combine the effects of the precipitation and the static factors to indicate and rank basins prone to flooding given the current or forecast precipitation.

2.2. Flash Flood Model (FFM)-Calibration and validation of the FFI can be accomplished with the aid of a physically-based runoff model. The technique will be two-fold. 1) The FFI will be compared to the FFM to identify whether the FFI has reproduced the behavior of the model considering that within the FFI the physics of the model have been replaced by simplified parameters and relations. 2) The FFM and FFI will be compared to an observed stage to identify the relative skill index of the FFM and FFI in rank ordering events in terms of peak discharge. Comparisons 1) and 2) will show whether the FFI can accurately rank storm events in terms of the flood response.

<u>Prospectus for Future Research</u>

1. Coupling the WSR-88D in realtime to the FFI and FFM raises questions such as:

a. What time intervals related to number of volume scans are sufficient for predicting the response of a watershed to intense rainfall?

b. What AMBER basin size is best for sampling the resolution of the radar together with the spatial structure of the storm event?

c. How best to formulate the functional relationship using neural networks, principal components analysis, analytical hierarchical processes.

d. Can a distributed-parameter hydrologic model run in realtime coupled to an operational WSR-88D to provide useful flood forecasts.
2. With future experiments and prototyping of dual-pole radar, river basin discharge offers a third instrument for validation. The areal raingage (river basin) offers a third data point for resolving radar-gage errors.
3. The adjoint of the FFM provides an opportunity to understand the relative sensitivity of the parameters responsible for producing flash floods when there is intense rainfall.
a. How do precipitation estimates produced by the WDSS-II improve the calibration validation and forecast skill of the FFM applied to a river basin?
b. Can we use the adjoint to estimate rainfall based on observed hydrographs and the inverse model?

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1 Much of this research and initial concepts were developed while on sabbatical during the 1998-99 academic year. Support and collaboration with Kenneth Howard and Ami Arthur in the Mesoscale Research Group, and with Michael Eilts and J.T. Johnson is gratefully appreciated.
2nd National Quantitative Precipitation Estimation (QPE) Workshop, April 13-15, 1999, COMET, Boulder, CO.

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6d. SPC Heavy Rain Mesoscale Discussion

(Jon Racy, SPC)

Historically, the Storm Prediction Center (SPC) has been responsible for issuing guidance products associated with severe thunderstorms and tornadoes. However, during the past couple of years, SPC has diversified and become an all hazards weather branch. In addition to the convective products, guidance is provided for hazardous winter weather, fire weather and heavy rainfall.

The main purpose of the SPC's Heavy Rain MD (MKCSWOMCD) is to alert SPC customers of evolving mesoscale atmospheric processes prior to the occurrence of heavy rains and/or provide a measure of confidence for a heavy rain event. The SPC's guidelines for issuing a heavy rain MD consist of one of the following: 1) Rainfall rates up to 3 inches per hour are expected with slow moving convection (i.e. storms moving at 10 knots or less), 2) rainfall amounts of at least 2 inches are expected at any one location within one hour, 3) rainfall rates of at least 1 ½ inches are expected to last at least 3 hours with a total rainfall of at least 4.5 inches, or 4) the forecast of an end to a heavy rain event.

The Heavy Rain MD will contain the expected location, rainfall rates, duration and , most importantly, the reasoning for the forecast heavy rain episode. Each discussion is typically written for a 0-3 hour time frame and will concentrate on those areas where the most significant heavy rains are expected to occur. This product is intended to provide adequate lead time to the WFO forecaster prior to the occurrence of the heavy rain event. The heavy rain MD is written for the most significant heavy rainfall area and is not intended to focus on large areas of heavy rain or be a QPF product.

If heavy rains have already occurred, a heavy rain MD usually will not be written. However, if heavy rain is occurring and one of the following conditions are present, then a heavy rain MD may be disseminated. Those conditions include: 1) Changing meteorological parameters that indicate an end to heavy rains, 2) a heavy rain episode that may have possibly been overlooked within an area of severe thunderstorms, 3) regeneration of new storms with heavy rains are expected across the same area where recent heavy rains have occurred, or 4) when heavy rains are expected to continue and also shift into a different area.

The Heavy Rain MD's will be accompanied by a graphic. This graphic will be available via the Internet and can be accessed on the SPC webpage at www.spc.noaa.gov.

2nd National Quantitative Precipitation Estimation (QPE) Workshop

April 13-15, 1999

at the

Cooperative Program for Operational Meteorology, Education and Training (COMET)
Boulder, CO

***Goals for QPE Meeting*:**

1) Provide a brief summary of, and update as necessary, NWS QPE requirements for hydrologic forecasting, flood warning issuance, QPF, numerical modeling, statistical guidance, verification, and climate applications (note: a complete list of requirements valid in Nov 97 is provided in the summary of the 1st National QPE Workshop);

2) Review and discuss operational techniques for the optimal use of existing QPE products;

3) Review current applied research and product development activities for satisfying QPE requirements;

4) Review and discuss current/future AWIPS applications/decision tools which utilize QPE products;

5) Review current QPE training efforts/plans;

6) Develop group recommendations for:
   a) applied research, product development, and communications infrastructure needed to satisfy future QPE requirements;
   b) outline path(s) to the operational implementation of "a";
   c) opportunities for collaboration to achieve QPE goals;

Notes:

- The workshop will be held in the COMET classroom -- due to space limitations, the total number of participants must be restricted to 40.
- Speakers with special audiovisual needs should contact Michael Mercer NLT 30 March.
- Speakers in sessions 2-6 should allow **at least one-third** of their allotted time for discussion.
- A **fifteen dollar** registration fee will be collected Tuesday morning prior to the start of the workshop.
- To facilitate the generation of the workshop summary, presenters are requested to provide Michael Mercer a 1-2 page summary of their presentation in electronic format NLT 23 April.

Tuesday, April 13

8:15 am	Welcome	(LeRoy Spayd /OM)
8:20 am	Opening Remarks/Workshop Overview	(Mercer, Gurka & Graziano/OM)

Session 1: QPE Requirements/Applications

Chairperson: Jim Gurka/OM

8:30 am	Session Overview Review of Existing NWS QPE Requirements/Applications	(Tom Graziano/OM)
9:00 am	Implementation of a National QPF Verification Program: QPE Needs and Issues	(Brett McDonald/HPC)
9:30 am	Group Discussion	(Jim Gurka/OM)
10:00 am	BREAK	

Session 2: Operational Application of WSR-88D and Satellite-Based Rainfall Estimates: Lessons learned and suggestions for most effective use within AWIPS

Chairperson: Andy Edman/WR

10:20 am	Session Overview	(Andy Edman)
10:45 am	Eastern Region	(Peter Gabrielsen)
11:10 am	Southern Region	(Jerry Nunn)
11:35 am	LUNCH	
12:30 pm	Map Discussion	(Matt Kelsch/COMET)
12:45 pm	Central Region	(Noreen Schwein)
1:10 pm	Western Region	(Andy Edman)
1:35 pm	Alaska Region	(Jeff Perry)
2:00 pm	Pacific Region	(Paul Jendrowski)
2:25 pm	Session Summary and Discussion	(Andy Edman)
2:50 pm	BREAK	

Session 3: WSR-88D Based QPE

Chairperson: Don Burgess/OSO

3:15 pm	Multi-Sensor (Stage I-III) QPE Products and Supporting Algorithms: Current Status and Future Direction	(Jay Breidenbach/OH)
4:00 pm	Precipitation Processing Subsystem (PPS) and ORPG: Current Status and Near-Term Improvements	(Tim O'Bannon/OSO)
4:45 pm	NCEP Stage IV Multisensor Precipitation Analysis	(Mike Baldwin/NCEP)
5:30 pm	***End of Day 1***	

Wednesday, April 14

8:00 am	Dual Polarization Rainfall Estimation: Open Systems Polarimetric Upgrade — Status and Plans	(Dusan Zrnic/NSSL)
8:40 am	Validation of Radar-Based QPEs Using Stream-Discharge Calculations and Observations for the Buffalo Creek, Colorado 1996 Flash Flood	(Tom Warner/UCAR)
9:05 am	Results of the NCAR Program in Radar Rainfall Estimation.	(Ed Brandes/NCAR)
9:30 am	Snowfall Estimation Using Radar and Snow Gages	(Roy Rasmussen/NCAR)
9:55 am	BREAK	
10:20 am	USBR Snow Accumulation Algorithm	(Ed Holroyd/USBR)
10:45 am	The Local Analysis and Prediction System (LAPS)	(Steve Albers/FSL)
11:10 am	Session Summary and Group Discussion	(Don Burgess/OSO)
11:45 am	LUNCH	
12:45 pm	Map Discussion	(Matt Kelsch/COMET)

Session 4: Satellite-Based Rainfall Estimation

Chairperson: Rod Scofield/NESDIS

Storm/Mesoscale Estimates

1:00 pm	Background and Near-term Development Efforts -- Interactive Flash Flood Analyzer (IFFA) -- Auto-Estimator/Verification -- Multi-Sensor and Multi-Spectral Products and Supporting Algorithms	(Rod Scofield/NESDIS)
1:50 pm	Using Microwave Imagery to Generate a Tropical Rainfall Potential (TRaP) Product	(John Paquette/NESDIS)
2:15 pm	Ideas for Integration of Multi-Sensor Data for Heavy Rainfall Estimation.	(Bob Rabin & Ken Howard/NSSL)
2:40 pm	Overlay of Satellite and Radar Imagery for Precipitation Estimation	(Eric Hilgendorf/CIRA)
3:05 pm	BREAK	
3:35 pm	Integration of Lightning Data to Improve SPEs	(Steve Goodman/NASA)

Global Estimates

4:00 pm	Recent Results in Satellite Precipitation Estimation Using Geosynchronous IR and Low-Orbit Microwave Data in Combination	(Bob Adler/NASA)
4:45 pm	Session Summary and Group Discussion	(Rod Scofield/NESDIS)
5:15 pm	***End of Day 2***	

Thursday, April 15

Session 5: Rainfall Estimation in Data Sparse Complex Terrain

Chairperson: John Schaake

8:00 am	Session Overview	(John Schaake/OH)
8:05 am	Mountain Mapper	(Gregg Rishel/WRH/HSD)
8:30 am	Atmospheric Models (Simulation and Prediction)	(Mike Baldwin/NCEP)
8:55 am	Suggestions for the Future	(John Schaake/OH)
9:15 am	Session Summary and Group Discussion	(John Schaake/OH)
9:45 am	BREAK	

Session 6: Integrated Systems, Products, and Training

Chairperson: Roger Pierce/OH

10:10 am	Session Overview	(Roger Pierce/OH)
10:15 am	WFO Hydrologic Forecast System (WHFS)	(Roger Pierce/OH)
10:40 am	Areal Mean Basin Estimated Rainfall (AMBER) Program	(Bob Davis/WSFO Pittsburgh,PA)
11:05 am	System for Convection Analysis and Nowcasting (SCAN)	(Stephan Smith/OSD)
12:00 pm	LUNCH	
1:00 pm	Map Discussion	(Matt Kelsch/COMET)
1:15 pm	NSSL Flash Flood Development Efforts	(Ken Howard & Baxter Vieux/ NSSL)
1:40 pm	SPC Heavy Rain Mesoscale Discussion	(Jon Racy/SPC)
2:05 pm	Integrated Sensor Training	(Tony Mostek/OM-COMET)
2:30 pm	COMET QPE/QPF PDS	(Jim Gurka/OM)
2:45 pm	Session Summary and Group Discussion	(Roger Pierce/OH)
3:10 pm	BREAK	

Session 7: Workshop Summary and Recommendations

3:30 pm	Workshop Summary	(Gurka, Graziano and Mercer/OM)
4:00 pm	Recommendations/Action Items	(Gurka, Graziano and Mercer/OM)
4:45 pm	***Adjourn***	

Meeting Participants:

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